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SPECIAL ISSUE: STUDIES ON CANADIAN AMPHIBIANS AND REPTILES
IN HONOUR OF DR. FRANCIS COOK. PART 1.

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COVER: Studies on Canadian Amphibians and Reptiles in Honour of Dr. Francis Cook. Centre: Dr. Francis Cook (photo: Brian Coad). See Editorial on pages 1–3. The inset photos (clockwise from top right) are: Northern Pacific Rattlesnake (*Crotalus o. oreganus*; photo: Karl Larsen; see article on pages 30–35), Spotted Turtle (*Clemmys guttata*; photo: David Seburn; see article on page pages 18–19), Fowler's Toad (*Anaxyrus fowleri*; photo: Katherine Yagi; see article on pages 46–52), Common Gartersnake (*Thamnophis sirtalis*; photo: William Halliday; see article on pages 25–29), and Painted Turtle (*Chrysemys picta*; photo: Patrick Moldowan; see article on pages 20–24).

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THE OTTAWA FIELD-NATURALISTS' CLUB

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Introduction to the Special Issue on herpetology in Canada

It is our great pleasure to introduce this special issue of *The Canadian Field-Naturalist* (CFN), which focusses on herpetology (the study of amphibians and reptiles) in Canada. This special issue has a wide range of articles and notes covering a large diversity of amphibians and reptiles in Canada. The last special issue of CFN was in 1999 (see Cook [1996] for a history of special issues and *The Canadian Field-Naturalist* [1998] for a list of the special issues 1995–1999).

This special issue is dedicated to Dr. Francis Cook. Francis has made a large mark on herpetology in Canada, so it is extremely fitting that we dedicate this special issue to him. This issue is also extremely timely: Francis was added to the Order of Canada in 2018 (Governor General of Canada 2018), and many of the reasons behind that nomination were related to his career as a herpetologist. Francis turned a life-long interest in amphibians and reptiles (Figure 1) into a remarkable career in herpetology. Francis authored 16 books, book chapters, and monographs on herpetology, and authored 47 journal articles on herpetology in a variety of different journals, including many in CFN.

Included among his publications is his classic book *An Introduction to Canadian Amphibians and Reptiles* (Cook 1984). His published herpetological contributions focussed on the diversity of amphibians and reptiles across Canada. He has published on every major group of amphibians and reptiles that live in Canada, including frogs, toads, salamanders, turtles, snakes, and lizards, and has published on a variety of topics, including taxonomy and biogeography. Francis has also demonstrated his broad knowledge of herpetology by reviewing nearly 100 different books on herpetology. Part II of this special issue will contain a bibliography of his publications.

Francis has been very involved in the conservation of amphibians and reptiles through his involvement with the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Francis was the chairperson of the COSEWIC subcommittee for amphibians and reptiles between 1981 and 1994, during which time he edited 13 COSEWIC reports on amphibians and reptiles. He has also been a reviewer for COSEWIC since 1994.



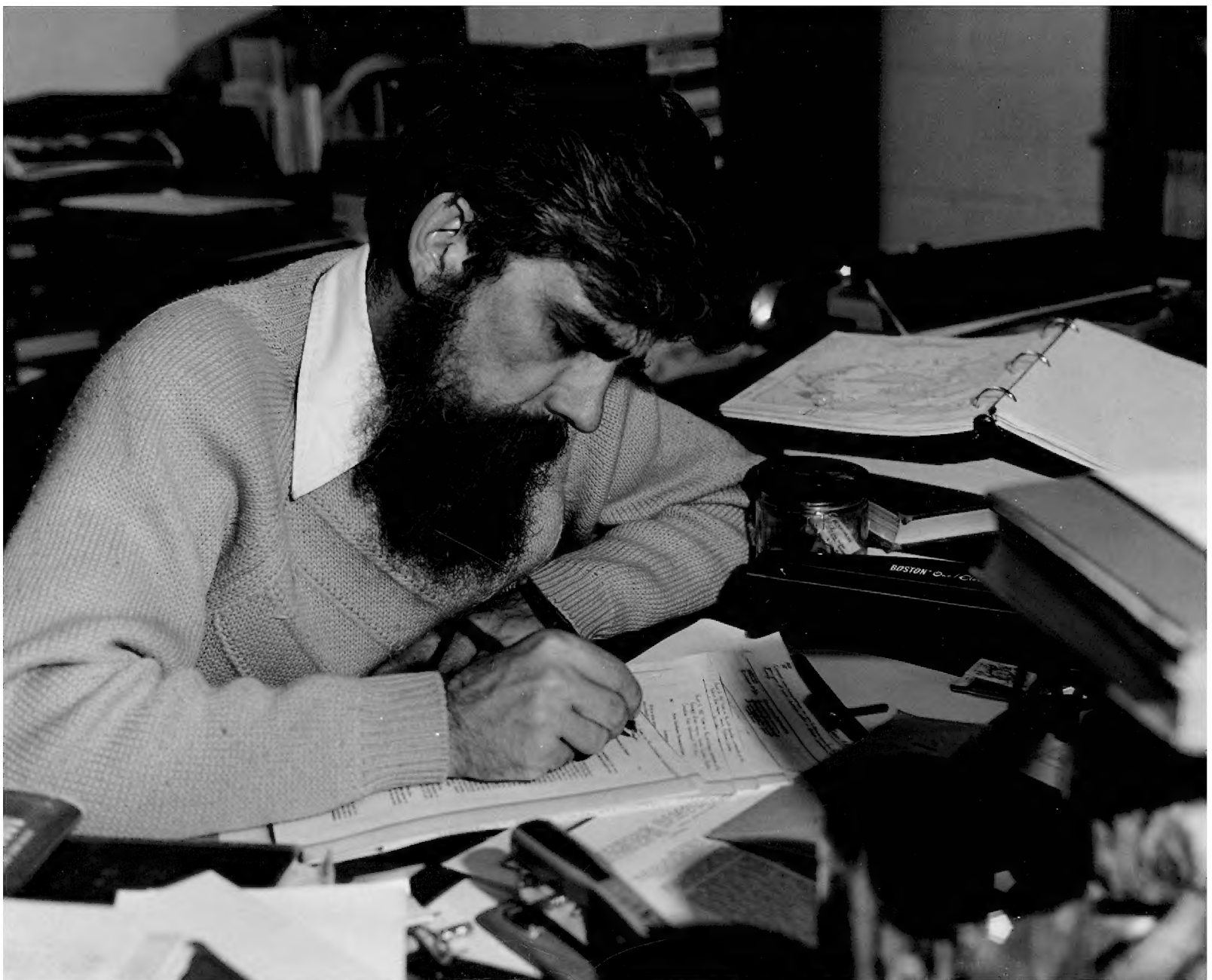
FIGURE 1. Francis Cook with an Eastern Foxsnake (*Pantherophis gloydi*) collected from Long Point, Ontario, by Francis and Sherman Bleakney (then Curator of Herpetology), 28 August 1956. Photo: S. Bleakney.

Finally, Francis's tenure as Curator of the Herpetology Section for the Canadian Museum of Nature from 1960 to 1991, and Curator Emeritus and Research Associate since 1994, has led to an enormous contribution to the field of herpetology. Francis helped build the herpetology collection from 14 000 to 133 000 specimens, which is the largest collection of Canadian herpetological specimens in the world. Francis's knowledge of these herpetological museum specimens has helped countless graduate students and researchers. More than just a curator of specimens, Francis has been a curator of knowledge (Figure 2). Before the age of scholarly search engines, Francis was an amazing resource for knowing the herpetological literature, including not only journal articles, but also student theses. Francis was, and still is, the person to talk to when reviewing the herpetological literature.

In addition to honouring Francis Cook's many contributions to herpetology, we especially want to recognize his long dedication to CFN. Francis was the Editor-in-Chief of CFN for an impressive 34 years, making him the longest serving editor in the journal's 100+ year

history. Francis first took on the editorial reins from 1962 to 1966, a time long before email and web submission of manuscripts. He stepped forward again in 1981 to edit the journal, remaining as the Editor-in-Chief until 2010. In total, Francis edited 35 volumes of CFN. After stepping down as the Editor-in-Chief, Francis continued on as the Associate Editor for herpetology and tributes from 2011 to 2016 (see Catling *et al.* 2016).

After conceiving the idea of this special issue, we put out a call for papers to Canadian herpetologists, including to members of the Canadian Herpetological Society, and they did not disappoint. Twenty-two articles and notes on all aspects of herpetology in Canada are part of this special issue. In fact, we received so many submissions that we had to split the special issue into two issues of CFN: 132(1) and 132(2). Eight articles and notes focus on turtles, six on snakes, four on frogs and toads, three on salamanders, and one is a checklist of amphibians and reptiles; we did not receive any submissions on lizards. These articles also represent the geographic breadth of Canada, with articles from the Mari-



Francis R. Cook at his desk December 1974

FIGURE 2. Francis Cook at work at the Canadian Museum of Nature, 1974. Photo: Canadian Museum of Nature.

times, eastern Canada, the Prairies, the West Coast, and even northern Canada.

In Part I of the special issue we have three articles and nine notes describing patterns of colouration (McAlpine and Gilhen), updates to species distribution (Gilhen and Power; Power and Gilhen), various aspects of fitness (Eye *et al.*; Gregory and Farr; Halliday and Blouin-Demers; Seburn), habitat use (Green and Yagi; Slough and deBruyn), behaviour (LeGros), sex-bias in capture rates (Moldowan *et al.*), and by-catch (Lennox *et al.*). Species described in this issue include three turtle species—Snapping Turtle (*Chelydra serpentina*), Painted Turtle (*Chrysemys picta*), and Spotted Turtle (*Clemmys guttata*); five snake species—Common Gartersnake (*Thamnophis sirtalis*), Western Terrestrial Gartersnake (*Thamnophis elegans*), Great Basin Gophersnake (*Pituophis catenifer deserticola*), Northern Pacific Rattlesnake (*Crotalus o. oreganus*), and Western Yellow-bellied Racer (*Coluber constrictor mormon*); three species of frogs and toads—Spring Peeper (*Pseudacris crucifer*), Fowler's Toad (*Anaxyrus fowleri*), and Western Toad (*Anaxyrus boreas*); and two salamander species—Eastern Red-backed Salamander (*Plethodon cinereus*) and Mudpuppy (*Necturus maculosus*).

Part II of the special issue will contain seven articles and three notes. Topics include habitat use (Atkinson-Adams *et al.*; Cairns *et al.*; Edkins *et al.*; Marchand *et al.*; Powell *et al.*), predation (Karson *et al.*), range expansions and species checklists (Choquette and Jolin; Rashleigh and Crowell), toxicology (de Solla and Gugelyk), and a variety of natural history observations (Cairns *et al.*; Davy *et al.*; Powell *et al.*). Species described in that issue will include three turtle species—Snapping Turtle, Western Painted Turtle (*Chrysemys picta bellii*), and Spiny Softshell Turtle (*Apalone spinifera*); two snake species—Bullsnake (*Pituophis catenifer sayi*) and Red-bellied Snake (*Storeria occipitomaculata*); one frog species—Spring Peeper; and

one salamander species—Long-toed Salamander (*Ambystoma macrodactylum*).

Herpetology is alive and well in Canada, with herpetologists studying interesting and important aspects of the natural history and ecology of amphibians and reptiles across the country. This special issue highlights the research being conducted by a subset of these herpetologists and, just like with Francis Cook's research, there is a great diversity of what herpetologists are studying in this country.

WILLIAM D. HALLIDAY, Guest Editor and Online
Journal Manager, *The Canadian Field-Naturalist*
Associate Conservation Scientist,
Wildlife Conservation Society Canada
and

DAVID C. SEBURN
Guest Editor and Associate Editor,
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Freshwater Turtle Specialist,
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Snapping Turtle—Tortue serpentine—turtle mi' kjikj (snapping; *Chelydra serpentina*), added to the herpetofauna of Cape Breton Island, Nova Scotia, Canada

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Abstract

Snapping Turtle (*Chelydra serpentina*) is native to mainland Nova Scotia, but its status on Cape Breton Island has been uncertain. Although it was recorded from Cape Breton Island as early as 1953, until 1984, it was known from only three widely scattered locations. Since that time, additional reports received from the public by Nova Scotia Department of Natural Resources and the Nova Scotia Museum of Natural History suggest that the species is native to Cape Breton Island. Thus, we are adding Snapping Turtle to the native herpetofauna of Cape Breton Island, Nova Scotia.

Key words: Snapping Turtle; *Chelydra serpentina*; herpetofauna; Mira River watershed; Cape Breton Island; Nova Scotia; Canada

Snapping Turtle (*Chelydra serpentina*; Figure 1), is native to mainland Nova Scotia. It was first recorded on Cape Breton Island in 1953 when a large adult was reported from the beach at Port Hood, Inverness County (Bleakney 1958; Gilhen 1984). In 1977, two additional specimens were collected from Richmond and Cape Breton counties (Gilhen 1984). Thus, until 1984, the species was known only from these three widely scattered locations, and the individuals were presumed to be released or escaped captive turtles originating from the mainland (Gilhen 1984).

Since 1984, reports received from the public by the Nova Scotia Department of Natural Resources and the Nova Scotia Museum of Natural History show that the

species is much more widely distributed than believed earlier. Detailed investigation of all reports of Snapping Turtle between 1953 and 2017 ($n = 75$) has provided a much clearer picture of the distribution of this species on Cape Breton Island, particularly in the Mira River watershed (Figure 2; Power and Gilhen 2018). These reports include adult turtles, especially nesting females, as well as juveniles (Figure 3). On 12 July 2006, we excavated the first documented nest of Snapping Turtle on Cape Breton Island at Intervale Road, Huntington (Mira River watershed), Cape Breton County (Figure 4).

Bleakney (1958) and Gilhen (1984) discussed the zoogeography of the herptiles of Nova Scotia in the context of land connections to the islands of the Gulf of St. Lawrence during the postglacial period. Evidence for a land connection from Cape Breton Island to mainland Nova Scotia during that period (~13 000–8000 years ago) is well documented (Shaw *et al.* 2002). Another freshwater turtle, Wood Turtle (*Glyptemys insculpta*), has long been recognized as a native species on Cape Breton Island (Gilhen 1984). Based on current understanding of the distribution and ecology of Snapping Turtle in both eastern Canada and elsewhere, we conclude that it (along with Wood Turtle), arrived in Cape Breton via a land bridge during the postglacial period and is native to Cape Breton Island (Power and Gilhen 2018). Therefore, we are adding Snapping Turtle to the herpetofauna of Cape Breton Island, Nova Scotia. We present an updated taxonomic list (after Crother 2008) of amphibians and reptiles of Cape Breton Island, Nova Scotia, Canada (Table 1).



FIGURE 1. Adult Snapping Turtle (*Chelydra serpentina*) searching for a nest site at Intervale Road, Huntington, Cape Breton County, Nova Scotia, on 25 June 2014. Photo: Terry Power.



FIGURE 2. Centre of the known distribution of Snapping Turtle (*Chelydra serpentina*) in the Mira River watershed on Cape Breton Island, Nova Scotia, Canada. Map of Nova Scotia by Nick Deagle, Nova Scotia Department of Natural Resources. Contains information licensed under the Open Government Licence – Nova Scotia.



FIGURE 3. Juvenile (13-year-old) Snapping Turtle (*Chelydra serpentina*) observed at Petersfield Provincial Park, Cape Breton County, Nova Scotia on 24 July 2013. Photo: Terry Power.



FIGURE 4. a. The first documented nest of Snapping Turtle (*Chelydra serpentina*) on Cape Breton Island, excavated on 12 July 2006 at Intervale Road, Huntington (Mira River watershed), Cape Breton County with MacKinnon Lake (a tributary of Salmon River) in the background; b. The same nest. Photos: Terry Power.

TABLE 1. Updated taxonomic list of amphibians and reptiles of Cape Breton Island, Nova Scotia, Canada (styled as in Crother 2008).

CAUDATA — SALAMANDERS
<i>Notophthalmus</i> Rafinesque, 1820 — EASTERN NEWTS
<i>Notophthalmus viridescens viridescens</i> (Rafinesque, 1820) — Red-spotted Newt
<i>Ambystoma</i> Tschudi, 1838 — MOLE SALAMANDERS
<i>Ambystoma laterale</i> Hallowell, 1856 — Blue-spotted Salamander
<i>Ambystoma maculatum</i> (Shaw, 1802) — Spotted Salamander
<i>Hemidactylium</i> Tschudi, 1838 — FOUR-TOED SALAMANDERS
<i>Hemidactylium scutatum</i> (Temminck and Schlegel in Von Siebold, 1838) — Four-toed Salamander
<i>Plethodon</i> Tschudi, 1838 — WOODLAND SALAMANDERS
<i>Plethodon cinereus</i> (Green, 1818) — Eastern Red-backed Salamander
ANURA — FROGS
<i>Anaxyrus</i> Tschudi, 1845 — NORTH AMERICAN TOADS
<i>Anaxyrus americanus americanus</i> (Holbrook, 1836) — Eastern American Toad
<i>Pseudacris</i> Fitzinger, 1843 — CHORUS FROGS
<i>Pseudacris crucifer</i> (Weid-Neuwied, 1838) — Spring Peeper
<i>Lithobates</i> Fitzinger, 1843 — AMERICAN WATER FROGS
<i>Lithobates clamitans</i> (Latreille, 1801) — Green Frog
<i>Lithobates clamitans melanota</i> (Rafinesque, 1820) — Northern Green Frog
<i>Lithobates palustris</i> (LeConte, 1825) — Pickerel Frog
<i>Lithobates pipiens</i> (Schreber, 1782) — Northern Leopard Frog
<i>Lithobates septentrionalis</i> (Baird, 1854) — Mink Frog
<i>Lithobates sylvaticus</i> (LeConte, 1825) — Wood Frog
SQUAMATA — SNAKES
<i>Storeria</i> Baird and Girard, 1853 — NORTH AMERICAN BROWNSNAKES
<i>Storeria occipitomaculata</i> (Storer, 1839) — Red-bellied Snake
<i>Storeria occipitomaculata occipitomaculata</i> (Storer, 1839) — Northern Red-bellied Snake
<i>Thamnophis</i> Fitzinger, 1843 — NORTH AMERICAN GARTERSNAKES
<i>Thamnophis sirtalis</i> (Linnaeus, 1758) — Common Gartersnake
<i>Thamnophis sirtalis pallidulus</i> Allen, 1899 — Maritime Garter Snake
<i>Diadophis</i> Baird and Girard, 1853 — RING-NECKED SNAKES
<i>Diadophis punctatus</i> (Linnaeus, 1766) — Ring-necked Snake
<i>Diadophis punctatus edwardsii</i> (Merrem, 1820) — Northern Ring-necked Snake
<i>Opheodrys</i> Fitzinger, 1843 — GREEN SNAKES
<i>Opheodrys vernalis</i> (Harlan, 1827) — Smooth Greensnake
TESTUDINES — TURTLES
<i>Chelydra</i> Schweigger, 1812 — SNAPPING TURTLES
<i>Chelydra serpentina</i> (Linnaeus, 1758) — Snapping Turtle
<i>Glyptemys</i> Agassiz, 1857 — SCULPTURED TURTLES
<i>Glyptemys insculpta</i> (LeConte 1830) — Wood Turtle
<i>Dermochelys</i> Blainville, 1816 — LEATHERBACK SEA TURTLES
<i>Dermochelys coriacea</i> (Vandelli, 1761) — Leatherback Sea Turtle*

*Annual visitor to the coast of Cape Breton Island and Nova Scotia.

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Status, distribution, and nesting ecology of Snapping Turtle (*Chelydra serpentina*) on Cape Breton Island, Nova Scotia, Canada

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Abstract

Based on current knowledge of the ecology and distribution of Snapping Turtle (*Chelydra serpentina*), both in eastern Canada and elsewhere, we conclude this species is native to Cape Breton Island. Seventy-two reports of Snapping Turtle from Cape Breton (1999–2017) indicate a range centred in the area south of Bras d'Or Lake. Date of oviposition ranged from 19 June to 10 July (median = 26 June) among 26 nests observed during 2012–2014. Clutch size for these nests was 23–65 eggs (mean = 46) and among 25 protected nests average rate of hatchling emergence was 21.5%. Time from oviposition to emergence of hatchlings ($n = 256$) was 75–120 days (mean = 87.2; SD = 9.0) among 20 nests. First emergence ranged from 9 September to 20 October (75–114 nest days; mean = 90) and last emergence ranged from 13 September to 28 October (86–120 nest days; mean = 100). Duration of emergence ranged from one day (i.e., synchronous emergence; five nests) to 37 days (mean = 11 days). The number of days on which hatchlings emerged at a nest ranged from one to nine days (mean = 4 days). Maximum carapace length was 25.0–31.8 mm (mean = 29.0 mm) and maximum carapace width was 23.5–30.0 mm (mean = 27.0 mm) for 256 hatchlings that emerged from 20 protected nests. Mass of hatchlings was 4.9–9.9 g (mean = 7.8 g).

Key words: Snapping Turtle; *Chelydra serpentina*; status; distribution; nesting ecology; clutch size; hatching success; Cape Breton Island; Nova Scotia; Canada

Introduction

Snapping Turtle (*Chelydra serpentina*) is native to mainland Nova Scotia and was first recorded present on Cape Breton Island in 1953 when a large adult was reported from the ocean beach at Port Hood, Inverness County (Bleakney 1958; Gilhen 1984). However, until 1984, Snapping Turtle was known to be present in Cape Breton from only three widely scattered locations that were believed to be the result of released/escaped captive turtles (Gilhen 1984) and this view of the species' status has remained up until the present (COSEWIC 2008; Environment and Climate Change Canada 2016). Our observations, together with reports received from the public by both Nova Scotia Department of Natural Resources (NSDNR) and the Nova Scotia Museum (NSM) within the past two decades, indicate Snapping Turtle is much more widely distributed than earlier believed. Beginning in 1999, detailed investigation of all reports of Snapping Turtle was undertaken to better understand the status and distribution of this species in Cape Breton. On 12 July 2006, we excavated the first documented nest of Snapping Turtle in Cape Breton at Intervale Road, Huntington, Cape Breton County (Gilhen and Power 2018). From 2012 to 2014, we investigated the nesting ecology of this species at this site.

Snapping Turtle was assessed Special Concern by the Committee on the Status of Endangered Wildlife

in Canada in 2008 (COSEWIC 2008) and is listed as Special Concern under the Canadian *Species at Risk Act* in 2011 (SARA Registry 2018) with a proposed Management Plan drafted in 2016 (Environment and Climate Change Canada 2016). Snapping Turtle was listed Vulnerable under the Nova Scotia *Endangered Species Act* in 2013, but to date, the presence of a naturally occurring population has not been recognized on Cape Breton Island (COSEWIC 2008; Environment and Climate Change Canada 2016). This paper discusses the status of Snapping Turtle on Cape Breton Island, summarizes known distribution based on personal observations as well as records from NSDNR and NSM ($n = 75$; 1953–2017), and presents data on time of nesting, location of nests, clutch size, time of emergence of hatchlings, survivorship to emergence, and size of hatchlings for nesting areas located at Huntington, Cape Breton County, Nova Scotia.

Study Area

Cape Breton Island is located off northeastern mainland Nova Scotia, Canada, (approximately 45.5–47.0°N, 59.5–61.5°W) separated from the mainland by the Strait of Canso, an approximately 2 km wide stretch of ocean connecting the Gulf of St. Lawrence to the north with the Atlantic Ocean to the south (Figure 1). A permanent land connection between Cape Breton Island and main-

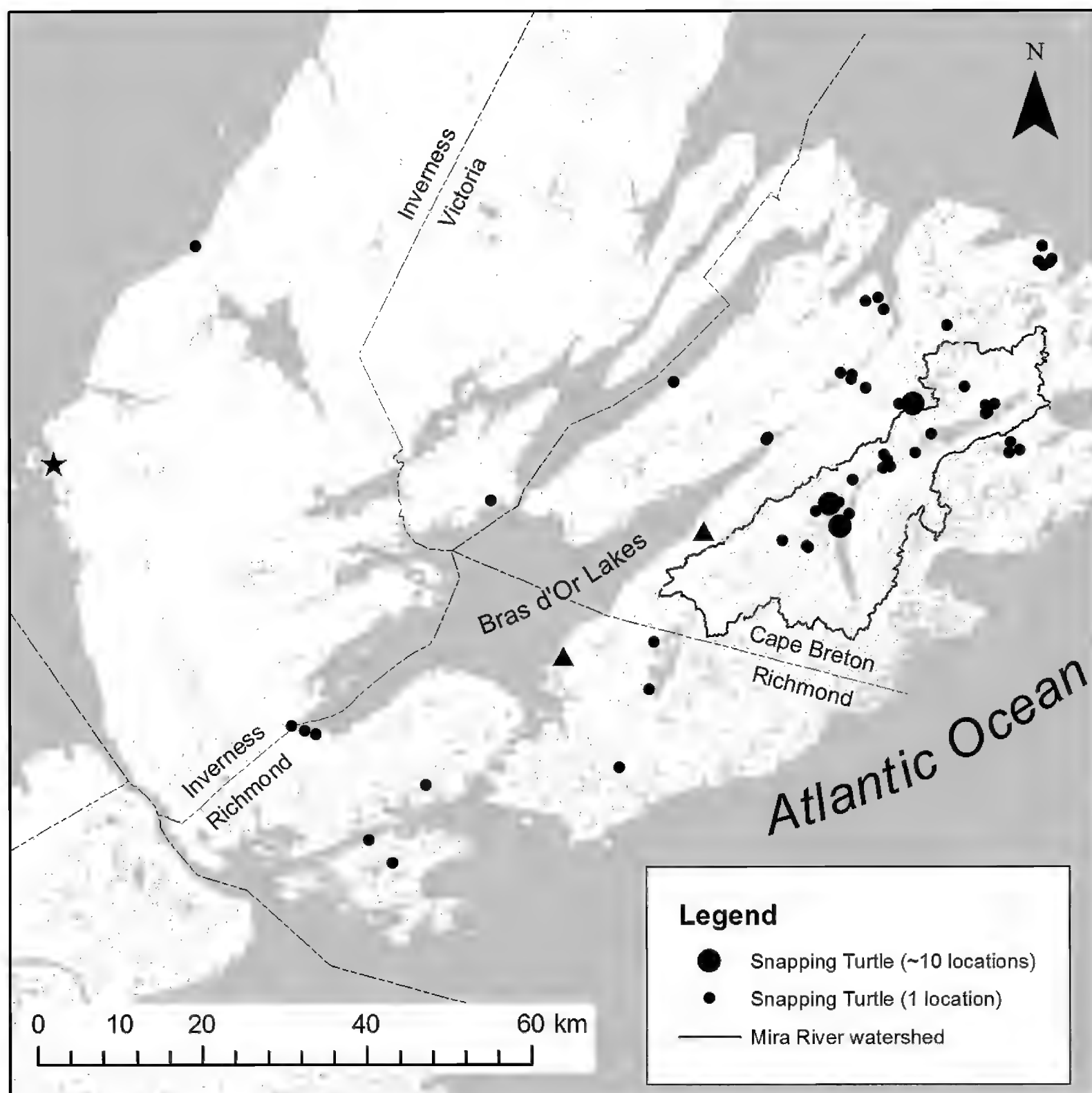


FIGURE 1. Distribution of records for Snapping Turtle (*Chelydra serpentina*) on Cape Breton Island, Nova Scotia, Canada 1953–2017 ($n = 75$) including a single record for 1953 (black star; Bleakney 1958; Gilhen 1984), two records for 1977 (black triangles; Gilhen 1984), and 72 records from 1999–2017 (black dots; this study). Contains information licensed under the Open Government License, Nova Scotia.

land Nova Scotia was completed in 1955 with the construction of the Canso Causeway. This narrow connection is a busy thoroughfare and a hostile environment with approaches through industrial lands, affording almost no opportunities for migration of freshwater turtles to or from Cape Breton Island.

Methods

All reports of Snapping Turtles for Cape Breton Island received from the public by NSDNR and NSM, as well as observations by NSDNR staff, between 1999 and 2017 were investigated and recorded. Interviews,

correspondence, photographs, and site visits were used to verify reports and collect accurate location data. Historical records by Bleakney (1958; one record) and Gilhen (1984; three records) were also reviewed. All locations were collated into NSDNR's Biodiversity Investigation Report system and exported to ArcMap GIS (Esri, California, USA) for mapping.

Surveys of known nesting areas at Huntington, Cape Breton County were conducted in June and July 2012–2014 to determine onset and duration of nesting and to locate nests. Three localized nesting areas were surveyed including two roadside nesting areas and one

natural riverine nesting area located on a gravel bar (island) in Salmon River near Intervale Road. Surveys were conducted on almost all days in the early part of the nesting season and more opportunistically thereafter. All visible nest attempts were global positioning system mapped and examined to determine if a nest was present. All nests discovered were immediately excavated, eggs were removed and carefully placed in the upright position, counted and returned to the nest in the same upright position, and the nest was re-buried. All nests were covered with 1 cm mesh galvanized hardware cloth screen fastened to 60 cm × 60 cm square wooden frames constructed of 38 × 89 mm wood and fixed to the ground using 16 mm rebar stakes, to prevent predation and to retain emerged hatchlings.

Beginning about 70 days after date of oviposition, all nests were surveyed daily to observe emerged hatchlings. Care was taken to replace each nest screen and fasten with rebar stakes to ensure that emerging hatchlings were not able to escape from under the screen undetected. All fully emerged hatchlings (Figure 2) were removed from under the protective screen. Maximum carapace length and width were measured to the nearest 0.1 mm using calipers, and weight measured to the nearest 0.1 g using Pesola® spring scales (Medio-Line No. 20010; Baar, Switzerland). Surveys were continued until mid-October 2012 and 2013, and mid-November 2014 and discontinued only after approximately two weeks of no further emergence of hatchlings and onset of cooler temperatures (2012 = 17 days; 2013 = 15 days; 2014 = 13 days). With one exception, no turtles emerged from a nest after two weeks of no emergence. One or two nests were excavated each year after the emergence period to examine condition of eggs and determine if live hatchlings were still present in the nest. All nest screens were removed for the winter and replaced again in May of the following year to monitor potential spring emergence.



FIGURE 2. Hatchling Snapping Turtle (*Chelydra serpentina*) emerged from a roadside nest on Intervale Road, Huntington, Cape Breton County, Nova Scotia, Canada, 11 September 2013. Photo: T. Power.

Results

Between 1999 and 2017 we investigated and verified 72 reports of Snapping Turtle on Cape Breton Island received from both the public and from the observations of NSDNR staff (Table 1). Except for two records for Inverness County (Inverness and West Bay), and one record for Victoria County (Jamesville), all records for Snapping Turtle on Cape Breton Island were in Cape Breton and Richmond Counties. These records indicate a distribution centred on an area of Cape Breton Island south of the Bras d'Or Lakes, with a notable concentration of records from tributaries of Mira River, Cape Breton County (Figure 1). The large number of observers ($n = 60$) submitting reports over an 18-year period and over a wide geographical area suggests there is no significant reporting bias. Within this larger area, many of the records are centred near the confluence of the Salmon River and Mira River and indicate that although Snapping Turtle nests widely across Cape Breton and Richmond Counties, the area of convergence of Salmon and Mira Rivers is the most important known nesting area. Only two records were located on Mira River which is tidal water: one a failed nest attempt and another a turtle carcass, both observed at Juniper Mountain on the southern shore of the Mira River.

Among 72 records of Snapping Turtle, 62 observations were made within the June–July nesting season and many of these were of confirmed (egg-laying observed) or probable (nest attempt without confirmed egg-laying) nesting females (Table 1). Among all records, only two were confirmed juvenile turtles based on carapace growth rings: one observation of a 13-year old turtle at Petersfield Provincial Park in Westmount, Cape Breton County, and one report of a juvenile turtle (estimated 14 years old from photograph) from near Camp Lake, Cape Breton County.

Snapping Turtles in Cape Breton nested in the gravel shoulder of a paved road ($n = 12$ nests), a natural riverine gravel bar ($n = 12$ nests), a semi-vegetated gravel quarry (one nest), and within a child's sandbox (one nest). Other reports of nesting turtles that were investigated ($n = 31$) showed nest attempts and probable nests located in other areas modified by development, including lawns, laneways, a horse paddock, and other areas cleared of vegetation (Table 1). Among 26 Snapping Turtle nests observed during three years (three in 2012; 10 in 2013; 13 in 2014), date of oviposition ranged from 19 June to 10 July (median = 26 June; Table 2). Dates of nesting for those nests monitored ($n = 26$) were 26–27 June 2012, 19–28 June 2013, and 25 June–10 July 2014. In addition, incidental observations of nesting activity (turtles nesting or making a nest attempt) on Cape Breton Island from 1999–2017 ($n = 31$) occurred as early as 17 June 2010 and as late as 26 July 2011 (Table 1). Onset of nesting in each year appeared to be synchronous but the length of the nesting season appeared to vary somewhat from year to year.

TABLE 1. Record number, location, date, sex, age, and behaviour for 75 records of Snapping Turtle (*Chelydra serpentina*) on Cape Breton Island, Nova Scotia, Canada 1953–2017.

Record	Date	Sex	Age	Location	Co.*	Map grid	UTME	UTMN	Behaviour
1013922	1/8/1953	U	A	Port Hood†, ‡	IN	11F5Z5	613478	5095301	unknown
1013923	18/5/1977	F	A	Campbells Brook‡	RI	23X5E3	675488	5071818	unknown
1013924	18/5/1977	M	A	Breac Brook‡	CB	23Z2G5	692560	5087013	unknown
207324	16/6/1999	U	A	Cow Bay Road	CB	14Y3F3	722238	5111961	unknown
214219	25/6/2001	U	A	Glace Bay	CB	43D3F16	730546	5110726	terrestrial movement
997633	22/5/2002	F	A	Glace Bay	CB	15V1C5	733818	5121662	terrestrial movement
225250	8/7/2002	F	A	Big Hill Road	CB	24Z1G2	731018	5096882	nest attempt
233014	6/7/2004	F	A	Grand Mira North	CB	24W2H5	709060	5087549	nest attempt
243552	7/7/2004	F	A	Huntington	CB	24W2G2	707971	5090500	nest attempt
243746	9/7/2004	F	A	Grand Mira North	CB	24W2H2	708959	5090533	nesting
997431	26/6/2005	F	A	Loch Lomond	RI	34Y1G2	685914	5067725	nesting
250324	4/7/2005	F	A	Grand Mira North	CB	24W2H5	709060	5087549	nesting
271432	28/6/2006	F	A	Huntington	CB	24W2H2	708959	5090533	nest attempt
271189	12/7/2006	U	E	Huntington	CB	24W2G2	707819	5090404	nest with eggs
252800	30/6/2007	U	A	Inverness	IN	12W1H2	630729	5121730	terrestrial movement
997428	2/7/2007	U	A	Huntington	CB	24W2G2	708024	5090142	unknown
231973	5/7/2007	F	A	New Boston	CB	24Z1F2	729723	5096524	nest attempt
231972	12/7/2007	U	A	Marion Bridge Hwy.	CB	14X5H1	716349	5102459	terrestrial movement
264421	20/7/2007	U	A	Glace Bay	CB	15V2C2	733968	5119246	terrestrial movement
264435	1/8/2007	U	A	Marion Bridge	CB	24X1F3	714949	5095684	terrestrial movement
231975	7/8/2007	F	A	Marion Bridge	CB	24X1B5	710697	5093166	terrestrial movement
257032	27/6/2008	F	A	Grand Mira North	CB	24W2H5	709164	5087477	nest attempt
997435	15/6/2009	U	A	Caribou Marsh Rd.	CB	14Y5B1	717992	5102587	terrestrial movement
401761	19/6/2009	F	A	Howie Centre	CB	14X4D5	712288	5104344	terrestrial movement
401830	19/6/2009	U	A	Caribou Marsh Rd.	CB	14Y5B2	718143	5101975	terrestrial movement
401831	9/7/2009	U	A	Caribou Marsh Rd.	CB	14Y5B1	718108	5102970	terrestrial movement
401834	17/7/2009	U	A	Albert Bridge	CB	14Z5C2	726867	5102290	terrestrial movement
403805	17/6/2010	F	A	Caribou Marsh Rd.	CB	14Y5B1	718108	5102970	nest attempt
407600	18/6/2010	F	A	Huntington	CB	24W2G2	707807	5090407	nest attempt
997444	18/6/2010	F	A	Huntington	CB	24W2G2	707947	5090382	nest attempt
407598	22/6/2010	F	A	Albert Bridge	CB	14Y1C2	718337	5096531	nest attempt
257122	26/6/2010	F	A	Huntington	CB	24W2G2	707971	5090500	nest attempt
257123	29/6/2010	F	A	Huntington	CB	24W2H2	708959	5090533	nest attempt
407597	2/7/2010	U	E	Huntington	CB	24W2G2	707818	5090394	nest with eggs
997425	8/7/2010	U	A	Jamesville	VI	23W2D1	666628	5090740	terrestrial movement
409130	16/7/2010	U	A	Marion Bridge	CB	24X1F2	714542	5096287	terrestrial movement
997426	17/7/2010	U	A	Marion Bridge	CB	24X1G3	715256	5094805	terrestrial movement
407668	20/7/2010	F	A	Blacketts Lake	CB	14X4A3	709264	5106233	terrestrial movement
997820	15/6/2011	U	A	Sydney Forks	CB	14X4B4	710503	5105510	terrestrial movement
257121	22/6/2011	F	A	Huntington	CB	24W2G2	707971	5090500	nest attempt
407738	26/7/2011	F	A	Huntington	CB	24W2G2	707875	5090395	nest attempt

TABLE 1. (Continued)

Record	Date	Sex	Age	Location	Co.*	Map grid	UTME	UTMN	Behaviour
992491	27/6/2012	U	A	Martinique	RI	33Z4A2	651691	5049953	terrestrial movement
997422	28/6/2012	F	A	Grand Mira South	CB	24X2B5	710044	5087747	nest attempt
997423	25/7/2012	F	A	Grand Mira South	CB	24X2A3	710232	5089030	nesting
997574	12/9/2012	U	A	Edwardsville	CB	14X2E6	712290	5114983	terrestrial movement
997395	24/5/2013	U	A	Glace Bay	CB	15V2D2	735003	5120006	terrestrial movement
997389	2/6/2013	U	A	Edwardsville	CB	14X2F5	713824	5115384	terrestrial movement
997397	18/6/2013	U	A	Salmon River Rd.	CB	24W3D2	705267	5084990	terrestrial movement
997402	18/6/2013	F	A	Northside East Bay	CB	14V5G5	700320	5098373	nest attempt
997404	24/6/2013	U	A	Albert Bridge	CB	14Z4A5	724333	5104525	terrestrial movement
997405	24/7/2013	U	J	Westmount	CB	14X3G1	714500	5113959	terrestrial movement
997473	20/8/2013	U	J	Camp Lake	CB	24W3A1	702104	5085865	terrestrial movement
997821	15/9/2013	U	U	Sydney Forks	CB	14X4C3	710598	5106014	aquatic basking
1000594	26/6/2014	U	A	Salmon River Rd.	CB	24W3D2	705103	5085177	terrestrial movement
1000563	10/7/2014	F	A	Albert Bridge	CB	14Z5C3	727142	5101410	nesting
1001650	15/7/2014	F	A	Grand Mira North	CB	24W2H5	709155	5087790	nest attempt
1004867	30/6/2015	F	A	Grand Mira South	CB	24X1F4	714428	5094636	nest attempt
1004878	3/7/2015	U	A	Loch Lomond	RI	23Y5H2	686496	5073463	terrestrial movement
1004875	12/7/2015	F	A	Grand River	RI	34Y2D6	682248	5058236	nest attempt
1004877	13/7/2015	U	A	New Boston	CB	24Z1F1	729948	5097763	terrestrial movement
1004601	16/7/2015	U	A	Albert Bridge	CB	14Z5C2	727932	5102430	terrestrial movement
1007091	13/5/2016	U	A	Marion Bridge	CB	14Y5D5	720295	5098817	terrestrial movement
1007090	26/5/2016	M	A	Glace Bay	CB	15V2C1	733415	5119801	terrestrial movement
1013868	27/6/2016	F	A	Grandique Road	RI	33Z4G5	654606	5046639	nesting
1007694	28/6/2016	F	A	Northside East Bay	CB	14V5G5	700156	5098137	nest attempt
1007749	29/6/2016	F	A	MacDonald Road	CB	24W2E3	706221	5089388	nest attempt
1013869	2/7/2016	F	A	Beaver Cove	CB	13Z4C4	688930	5105128	nesting
1008245	10/8/2016	U	A	Glace Bay	CB	15V2D2	734688	5119633	dead
1008261	12/8/2016	U	A	Grand Mira South	CB	24X1C6	714385	5094632	dead
1013853	18/6/2017	U	A	Dundee	RI	33Y2F1	645312	5062297	terrestrial movement
1012655	24/6/2017	U	A	Albert Bridge	CB	14Z5C3	726886	5101227	terrestrial movement
1013787	30/6/2017	F	A	Salmon River Rd.	CB	24W2G4	708343	5088116	nest attempt
1012894	9/7/2017	U	A	Cannes	RI	34V3D2	658712	5056118	terrestrial movement
1013851	10/9/201	U	A	Dundee	RI	33Y1D6	643968	5062718	terrestrial movement
1013854	2/7/2017	U	A	West Bay	IN	33Y1C5	642343	5063326	terrestrial movement

*CB (Cape Breton County), IN (Inverness County), RI (Richmond County), VI (Victoria County).

†Bleakney (1958).

‡Gilhen (1984).

TABLE 2. Date of oviposition, clutch size, number of hatchlings emerged, dates, duration of hatchling emergence, and hatchling size for 25 protected nests (256 hatchlings) of Snapping Turtle (*Chelydra serpentina*) in a study area at Huntingdon, Cape Breton County, Nova Scotia.

Nest ID	Nest date	Clutch size	Intact clutch size*	No. of hatchlings emerged	Hatch success (%)	First emergence date	Min. nest days	Last emergence date	Max. nest days	Duration of emergence (days)	No. of days hatchlings emerged	Mean		Mean hatchling mass (g) (SD)
												hatchling carapace length (mm) (SD)	hatchling carapace width (mm) (SD)	
2012-06-27-1	25/6/2012	42	42	est. 20	est. 47.6	est. 7-Sep-12								
2012-06-26-3	25/6/2012	40	40	0	0.0	N/A								
2012-06-26-2	25/6/2012	47	37	24	51.1	11/9/2012	78	28/9/2012	95	17	4	28.3 (0.6)	26.7 (0.9)	7.0 (0.6)
2013-06-19-1	19/6/2013	51	51	40	78.4	11/9/2013	84	25/9/2013	98	14	9	28.6 (0.9)	26.7 (1.0)	8.3 (0.5)
2013-06-19-2	19/6/2013	51	51	9	17.6	13/9/2013	86	13/9/2013	86	1	1	29.4 (0.8)	27.1 (0.8)	7.8 (0.4)
2013-06-19-3	19/6/2013	44	43	16	36.4	13/9/2013	86	22/9/2013	95	9	5	29.8 (0.7)	27.4 (0.8)	8.2 (0.3)
2013-06-19-4	19/6/2013	55	52	11	21.2	14/9/2013	87	23/9/2013	96	9	3	28.1 (0.8)	26.0 (1.3)	7.0 (0.6)
2013-06-19-5	19/6/2013	44	44	11	25.0	14/9/2013	87	23/9/2013	96	9	5	30.3 (0.9)	27.7 (1.3)	8.7 (0.5)
2013-06-24-1	24/6/2013	60	59	3	5.0	24/9/2013	92	24/9/2013	92	1	1	28.4 (0.6)	25.3 (0.9)	7.4 (0.5)
2013-06-24-2	24/6/2013	49	49	4	8.2	17/9/2013	85	20/9/2013	88	3	3	29.4 (0.5)	26.7 (0.8)	7.3 (0.3)
2013-06-28-1	28/6/2013	23	23	0	0.0	N/A	N/A		N/A	N/A	N/A	N/A		
2013-06-28-2	28/6/2013	45	45	2	5.0	20/10/2013	114	20/10/2013	114	1	1	27.9 (0.0)	25.3 (0.4)	5.8 (0.1)
2013-06-28-3	28/6/2013	52	52	24	46.2	14/9/2013	82	26/9/2013	94	12	7	28.7 (0.8)	26.8 (0.9)	7.6 (0.5)
2014-06-25-1	25/6/2014	37	37	20	54.1	14/9/2014	81	21/10/2014	118	37	7	29.2 (0.9)	27.7 (0.6)	8.2 (0.7)
2014-06-26-1	26/6/2014	64	63	24	37.5	9/9/2014	75	25/9/2014	91	16	7	29.0 (1.0)	27.8 (1.1)	7.4 (0.6)
2014-06-26-2	26/6/2014	42	37	3	7.1	22/9/2014	88	16/10/2014	112	24	3	29.8 (1.1)	27.6 (1.5)	7.7 (0.8)
2014-06-26-4	26/6/2014	40	40	28	70.0	19/9/2014	85	5/10/2014	101	16	9	30.1 (0.9)	27.4 (0.8)	9.0 (0.5)
2014-06-26-5	26/6/2014	40	40	1	2.5	30/9/2014	96	30/9/2014	96	1	1	N/A		
2014-06-30-1	30/6/2014	55	55	5	9.1	5/10/2014	97	21/10/2014	113	16	3	26.6 (0.6)	24.9 (0.2)	5.8 (0.4)
2014-06-30-2	30/6/2014	65	64	6	9.2	18/10/2014	110	28/10/2014	120	10	5	27.2 (0.3)	25.9 (0.4)	6.5 (0.4)
2014-06-30-3	30/6/2014	57	55	15	26.3	27/9/2014	89	12/10/2014	104	15	6	29.4 (0.5)	26.9 (0.9)	7.4 (0.5)
2014-06-30-4	30/6/2014	37	35	8	21.6	30/9/2014	92	3/10/2014	95	3	3	30.7 (1.1)	27.7 (0.6)	8.7 (0.6)
2014-07-03-1	3/7/2014	61	61	0	0.0	N/A	N/A		N/A	N/A	N/A	N/A		
2014-07-04-1	4/7/2014	36	36	2	5.6	11/10/2014	99	11/10/2014	99	1	1	25.8 (0.3)	23.7 (0.3)	5.2 (0.4)
2014-07-04-2	4/7/2014	28	28	0	0.0	N/A	N/A		N/A	N/A	N/A	N/A		
2014-07-10-1	10/7/2014	30	30	0	0.0	N/A	N/A		N/A	N/A	N/A	N/A		
Mean		46.0	45.0	10.2	21.5		90		100	11	4	2.9	2.7	7.8
SD		11.0	10.9	10.9	23.1		10		10	9	3	0.1	0.1	0.9
Min		2323	0	0.0		75		86	1	1	2.5	2.4	4.9	
Max		6564	40	78.4		114		120	37	9	3.2	3.0	9.9	
Count		2626	25	25		20		20	20	20	256.0	256.0	256.0	

*The number eggs left intact following oviposition, excavation, and replacement of the clutch (occasionally eggs were destroyed during oviposition or excavation of the nest).

Clutch size for 26 nests protected from predation with wire screen was 23–65 eggs (mean \pm SD: 46 ± 11 ; Table 2). Hatchlings emerged from 20 of 26 protected nests (76.9%); five nests did not produce hatchlings. An additional riverine nest was flooded during hatchling emergence but appeared to have had partial hatchling emergence. Among the 25 protected nests with a known outcome, the number of hatchlings that emerged ranged from 0 to 40 (10 ± 11). The proportion of a clutch that produced emerged hatchlings was 0–78.4% (21.5 ± 23.1).

Among 20 protected nests from which hatchlings emerged during 2012–2014, time from oviposition to emergence of a hatchling ($n = 256$; Table 2) was 75–120 days (87.2 ± 9.0). Time of first emergence ranged from 9 September to 20 October (75–114 nest days; 90 ± 10) and date of last emergence ranged from 13 September–28 October (100 ± 10). Duration of emergence at a nest ranged from one day (i.e., synchronous emergence; five nests) to 37 days for one nest (mean = 10 days). Among 20 protected nests, number of days on which hatchlings emerged ranged from one to nine (mean = 4).

A total of 256 hatchlings emerged alive from 20 protected nests (Table 2). An additional one and 12 hatchlings, respectively, were excavated and released alive from two of these nests on 11 October 2013. These 13 hatchlings were initially torpid within the nest due to cool temperatures late in the season but became active once removed from the nest, placed in the sun, and were subsequently released. These hatchlings may not have been able to emerge on their own, had the nest not been excavated. However, the latest date of hatchling emergence in 2013 was 11 days later (20 October) when two hatchlings emerged from one nest.

For 256 hatchlings that emerged from protected nests ($n = 20$), maximum carapace length was 25.0–31.8 mm (29.0 ± 1.2) and maximum carapace width was 23.5–30.0 mm (27.0 ± 1.1). Mass of hatchlings ranged from 4.9 to 9.9 g (7.8 ± 0.9).

Discussion

Snapping Turtle is native to mainland Nova Scotia (Bleakney 1958; Gilhen 1984) but the occurrence of this species on Cape Breton has been uncertain. Bleakney (1958) provides the first record for Snapping Turtle on Cape Breton Island, that of a large adult reported from the beach at Port Hood, Inverness County in 1953. Gilhen (1984) includes this record and two additional occurrences: one at Campbells Brook, Richmond County and another at Breac Brook, Cape Breton County, both observed on 18 May 1977. These three widely scattered locations were believed to be the result of released/escaped captive turtles (Gilhen 1984) and for 22 years, no further observations were recorded for this species on Cape Breton Island. Beginning in 1999, an effort was made to investigate all sightings received from the public by NSDNR and NSM. In addition,

NSDNR staff were encouraged to actively record sightings. The accumulated reports began to suggest the species was much more widely distributed than earlier believed and several nesting areas were identified.

Seventy-two verified reports of Snapping Turtle on Cape Breton Island from 1999–2017, together with personal observations, indicate a distribution centred on the area of Cape Breton and Richmond Counties south of the Bras d'Or Lakes (45.5–46.0°N), with a notable concentration of records from tributaries of Mira River, Cape Breton County. Within this larger area, most of the records are centred near the confluence of Salmon River and Mira River. The presence of an important nesting area here, including both riverine and roadside nests, on Salmon River and Intervale Road at Huntington, may largely account for the increased number of reports from this area as Snapping Turtle is highly aquatic, and most reported sightings are of females on land during the nesting season.

The current widespread occurrence and relative abundance of Snapping Turtle on Cape Breton suggests this species is likely native to the Island. The absence of records from 1953 to 1977 and again from 1977 to 1999 is troubling but may simply reflect gaps in searching for and reporting on this species. In this context, Bleakney (1958) discusses similar historical anomalies in documentation of herpetofauna in eastern Canada and elsewhere. The accumulation of reports of Snapping Turtle in Cape Breton since 1999 reflects an effort by the authors to search for reports for this species, to verify all reports received, and to encourage further reporting from observers including both the public and NSDNR staff. Snapping Turtle occurs widely in adjacent mainland Nova Scotia, New Brunswick, and Maine at similar latitudes to that of Cape Breton, so its presence here is not unexpected. Two species of herpetofauna with wide distributions on mainland Nova Scotia which are not native to Cape Breton, are Northern Painted Turtle (*Chrysemys picta*) and American Bullfrog (*Lithobates catesbeianus*). In contrast, Wood Turtle (*Glyptemys insculpta*) is native to both the mainland and Cape Breton Island (Gilhen 1984; Gilhen and Power 2018), even though the presence of this species here was not recognized earlier (Bleakney 1958). Bleakney (1958) discussed the postglacial immigration of amphibians and reptiles into eastern Canada and, based on isostatic land movements and seawater levels, concluded that Cape Breton Island was connected by a land bridge to the adjacent mainland of Nova Scotia between 16000 and 10000 years ago. Gilhen (1984) elaborates on the timing, connection, and isolation of geographic features in the Maritime provinces during the postglacial period and resultant impacts on present distributions of herpetofauna. More recently, Shaw *et al.* (2002) present evidence, based on isobase maps and a digital terrain model, to show a land connection from Cape Breton Island to mainland Nova Scotia from about 13000–8000 years before present (BP) with peak emer-

gence of Cape Breton Island at about 9000 years BP. Snapping Turtle is recognized as one of the dominant turtles within North American glacial age faunas and one of the first to invade following glacial retreat at the end of the Wisconsin (Holman and Andrews 1994).

Bleakney (1958) did not recognize the presence of turtles on Cape Breton, even though he reports on a visual sighting of Snapping Turtle by A.W. Cameron at Port Hood Beach, Inverness County in 1953. Bleakney (1958) suggested that turtles may have arrived too late to take advantage of a land bridge to Cape Breton (as well as Prince Edward Island) and presented a range map for the northern limit for freshwater turtles that excludes Cape Breton Island. However, Bleakney (1958) calculated an "Environmental Temperature Index" to estimate the northern limit for Snapping Turtle that includes Cape Breton Island. The approximate northern limit of distribution of Snapping Turtle in Cape Breton (46.0°N) is well within the range of populations studied elsewhere (e.g., 45.5°N in Ontario [Congdon *et al.* 2008]; 46.0°N in Michigan and 47.2°N in Minnesota [Ewert *et al.* 2005]; 53.0°N in Manitoba [Holman and Andrews 1994]). The tolerance of Snapping Turtle and its eggs to brackish water conditions, including habitation in coastal saltmarshes (Pope 1961; Kinneary 1992; Klemens 1993; Hunter *et al.* 1999), would enhance the ability of this species to colonize Cape Breton Island along a prehistoric land bridge with mainland Nova Scotia. Based on current knowledge of the ecology and distribution of Snapping Turtle, both in Eastern Canada and elsewhere, we conclude this species is native to Cape Breton Island and arrived here along with Wood Turtle via a land connection to mainland Nova Scotia about 10 000 years BP.

Snapping Turtle is known to nest in a variety of natural and disturbed substrates (Congdon *et al.* 2008). In Cape Breton, we recorded the species nesting on natural riverine gravel bars as well as a variety of sites modified by development, including gravel road verges, lawns, laneways, a horse paddock, a child's sand box, and other semi-vegetated areas. Turtles here appeared to choose unshaded nest sites, open to the sun, which may reflect an adaptation to hasten embryogenesis in this northern population, as suggested by Ewert *et al.* (2005). Within its extended range in North America, Snapping Turtle nests earlier in the south than further north (Iverson *et al.* 1997; Congdon *et al.* 2008). Warmer springs result in more rapid follicular development and egg maturation, and earlier onset of nesting (Congdon *et al.* 1987). Date of first observed nesting in Cape Breton (17 June) was somewhat later than in Nebraska (1–12 June; Iverson *et al.* 1997) and southeastern Michigan (22 May–12 June) where first nesting varied annually by 22 days and was significantly correlated with the amount of heat available in March, April, and May (Congdon *et al.* 1987). Obbard and Brooks (1987) used accumulation of heat units in a lake to predict onset of nesting and reported that even

though date of first nesting in north-central Ontario varied by 15 days over six years, variation in accumulation of heat units varied by only 7.5%. Nesting in Cape Breton (17 June–26 July), also near the northern limit of the species range (46.0°N), may be somewhat later than that reported for Algonquin Park, Ontario (26 May–7 July; Congdon *et al.* 2008), at a similar latitude (45.5°N).

Clutch size of Snapping Turtles in Cape Breton is large but within the range reported from locations elsewhere in the species range (Iverson *et al.* 1997; Congdon *et al.* 2008). Clutch size of eight nests at Grafton Lake, Queens County, in southwestern mainland Nova Scotia, was 19–41 eggs (Gilhen 1984). Hatchlings in Cape Breton emerged from 76.9% of protected nests. Total nest failure (failure of hatchlings to emerge = 19.2%) appears higher than reported for southeastern Michigan (egg infertility or failure of embryos to develop = 11.8%; Congdon *et al.* 1987). Hatching success among protected nests in Cape Breton (21.5%) was much lower than in north-central Ontario, at a similar latitude (73.2–85.2%; Riley and Litzgus 2013). Probability of survival in protected nests in Cape Breton was 0.215, whereas the probability of survival of unprotected nests (including a 70% predation rate) was 0.22 in Michigan (Congdon *et al.* 1987). Nest predation losses in the Michigan population over 17 years averaged 77% (Congdon *et al.* 1994). Clearly, the already low survivorship to emergence in protected nests in Cape Breton (comparable to that of unprotected nests in Michigan) would be much further reduced by predation. In nests of Snapping Turtle in Cape Breton, an average of 35 eggs in protected nests failed to produce hatchlings whereas in southeastern Michigan, an average of four eggs or embryos died in nests that escaped predation (Congdon *et al.* 1987). High nest failure and low hatchling survivorship to emergence, due to factors other than predation, suggest recruitment may be low in this northern population of Snapping Turtle in Cape Breton. Predated nests were observed in Cape Breton during both nesting and hatchling emergence. Often extended duration of emergence at nests in Cape Breton coupled with observed peaks in predation late in incubation elsewhere (Riley and Litzgus 2014) may facilitate increased predation pressure here.

Snapping Turtle in Cape Breton emerged in September and October, and as generally reported elsewhere (Congdon *et al.* 1987, 2008; Carroll and Ultsch 2007; Baker *et al.* 2013), no spring emergence was observed. Scattered reports of confirmed (Obbard and Brooks 1981; Parren and Rice 2004) or suspected (Bleakney 1963; Congdon *et al.* 1987) spring emergence are recorded for this species and have been linked to the insulating effects of unusually deep snow cover (Obbard and Brooks 1981) and an unusually mild winter (Parren and Rice 2004). Snapping Turtle hatchlings in Cape Breton were observed to emerge later (9 September–28 October) than reported further south (5–24 Septem-

ber in New Hampshire [Carroll and Ultsch 2007]; late August to early October in southeastern Michigan [Congdon *et al.* 1987]). Mean number of days from egg-laying to hatchling emergence in Cape Breton (mean = 87.2, range 75–120) was slightly lower than that reported for north-central Ontario at a similar latitude (~93 days; Riley and Litzgus 2013), and also for Michigan, further to the south (mean = 93.2, range 73–117; Congdon *et al.* 1987). Mean time to first emergence in Cape Breton was slightly shorter (90 days) than in a more southerly population in Indiana (94 days, range 90–97 days; Baker *et al.* 2013). Duration of emergence at a nest in Cape Breton, (mean = 11 days) may be longer than reported elsewhere. In Indiana, mean duration of emergence at a nest was eight days (range 1–20 days) and synchronous emergence occurred occasionally (Baker *et al.* 2013). Synchronous emergence in nests (25%) was much lower in Cape Breton than in southeastern Michigan (65%; Congdon *et al.* 1987).

Emergence of Snapping Turtle hatchlings in Cape Breton appears to be characterized by a high proportion of asynchronous emergence, a protracted duration of emergence at some nests (up to 37 days) as well as emergence on numerous days within the emergence period. Despite this, however, average time from oviposition to emergence may be shorter in Cape Breton than has been reported elsewhere. Both high and low incubation temperatures compromise survival and growth rates of Snapping Turtle hatchlings (Brooks *et al.* 1991). Bobyn and Brooks (1994) found that lower incubation temperature increased mortality and compromised growth and survival of hatchling Snapping Turtles and suggest this is an important determinant of the northern limit of this species, through reduced recruitment. Summer temperatures are thought to be the dominant factor limiting the northern distribution of herpetofauna in Canada (Bleakney 1958; Brooks 2007) and Snapping Turtle approaches the northern limit of its range in Cape Breton.

The relatively large and deep nests of Snapping Turtles likely contribute to the observed temperature differences within nests with depth which has been reported (Packard *et al.* 1985). Packard *et al.* (1987, 1998, 1999) discuss the importance of variation in thermal and to a lesser extent, hydric, conditions of incubating eggs of Snapping Turtle to both size and physiological condition of hatchlings. The high proportion of asynchronous emergence and extended duration of emergence for individual nests in Cape Breton may reflect differing hydric and, especially, temperature conditions within nests, exaggerated by already marginal incubation conditions experienced by this northern population.

Size of Snapping Turtle hatchlings in Cape Breton ($n = 256$; mean carapace length = 29.0 mm, range 25.0–31.8 mm; mean carapace width = 27.0 mm, range 23.5–30.0 mm; mean mass = 7.8 g, range 4.9–9.9 g) was similar to that of hatchlings in southeastern Michigan (mean carapace length = 29.1 mm, range 23.0–33.0 mm; mean

mass = 8.9 g, range 5.0–11.0 g; Congdon *et al.* 1987) and north-central Ontario (carapace length = 27.84 mm [males] and 29.47 mm [females]; mean mass = 9.03 g [males] and 9.68 g [females]; Riley *et al.* 2014). Within nests in Cape Breton, size of emerged hatchlings appears to decrease with both clutch size and date of hatchling emergence but further exploration of this relationship is needed.

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Note

Record longevity of a Spotted Turtle (*Clemmys guttata*)

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Abstract

Turtles are known for their longevity, but the maximum life span for many species remains unknown. Spotted Turtle (*Clemmys guttata*) can live for more than 30 years in the wild, but typical or maximum longevity has not been confirmed. As part of a long-term mark–recapture project in Ottawa, Ontario, near the species’ northern limit, an adult female was captured on 27 April 2017. It had first been marked on 11 June 1983, when it was an adult with 17 growth rings on its plastron. Based on the number of growth rings at first capture, and the intervening time, this turtle is a minimum of 51 years old, setting a longevity record for the species. Ten individuals in this population were at least 30 years old when last captured, including a male at least 41 years old. Few of these turtles have grown measurably since being marked in 1983, and it is likely that these minimum ages are underestimates of actual ages.

Key words: Spotted Turtle; *Clemmys guttata*; longevity

Turtles are widely known for their longevity and many species can live for decades in the wild (Gibbons 1987; Ernst and Lovich 2009). Lifespans greater than 50 or 60 years have been confirmed for Wood Turtles (*Glyptemys insculpta*; Brown *et al.* 2015) and Blanding’s Turtles (*Emydoidea blandingii*; Congdon *et al.* 2001). Anecdotal observations of turtles with dates carved into their shells suggest that Blanding’s Turtles can live more than 75 years (Brecke and Moriarty 1989) and Eastern Box Turtles (*Terrapene carolina*) more than 100 years (Ernst and Lovich 2009), assuming such dates are reliable. An understanding of typical adult longevity is important for calculating life history tables and determining effective conservation strategies for populations. Unfortunately, documenting the precise longevity of such long-lived animals is difficult because determination of ages for multiple individuals from a population requires a long-term mark–recapture study of known-age individuals, while most research studies are relatively short-term.

Spotted Turtle (*Clemmys guttata*) is a small turtle with a maximum recorded carapace length of only 14.25 cm (Ernst and Lovich 2009). The species is restricted to eastern North America from southern Ontario to northern Florida, where it makes use of a variety of shallow wetlands. Habitat loss remains a significant threat across its range (COSEWIC 2014), and Spotted Turtle is considered endangered in Canada (SARA Registry 2018) as well as globally (van Dijk 2011). Individuals can live for more than 30 years in the wild (Seburn 2003; Ernst and Lovich 2009), but few details have been published on longevity in this species in the wild. The estimated maximum longevity is 65 years for males and 110 years for females (Litzgus 2006).

A population of Spotted Turtles occurs in a 2500-ha sphagnum bog owned by the National Capital Commission in Ottawa, Ontario, Canada, near the species’ northern range limit (Cook *et al.* 1980). This population was first studied during a mark–recapture project in 1983 (Chippindale 1984). Captured turtles were marked by notching the marginal scutes with a file to assign unique identification codes (Cagle 1939). This work was continued in 1999 (Seburn 2003), and sporadic monitoring of the population has continued. Notches in the shells of Spotted Turtles marked in 1983 remain clear and unambiguous.

On 27 April 2017 during a survey of the bog, I captured an adult female Spotted Turtle that had been first caught and notched as an adult on 11 June 1983 (Chippindale 1984). In 1983, the turtle’s plastron was 9.7 cm long and had 17 growth rings. In 2017, 34 years later, its plastron was still 9.7 cm long and had a minimum of 17 faint growth rings. This turtle was presumably an adult in 1983 based on the number of growth rings and the fact that it did not grow in the subsequent 34 years; growth rates for adults are extremely low (e.g., Seburn 2003). Given the number of growth rings in 1983 and the number of intervening years, this turtle was a minimum of 51 years old in 2017. To the best of my knowledge, this is the oldest published age for a Spotted Turtle.

Counts of growth rings are known to underestimate the age of many species of turtles (Wilson *et al.* 2003) including adult Spotted Turtles (Litzgus and Brooks 1998). Adult Spotted Turtles in the study population grew by less than 1 mm and increased the number of growth rings by only 1.1, on average, from 1983 to 1999 (Seburn 2003). Given this lack of growth and addition

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of growth rings, there is no reason to think the turtle was only 17 years old when first marked, meaning this turtle could be considerably older than 51 years.

Other individuals in this population first marked in 1983 demonstrate longevity in excess of 30 years. An adult male first marked when it had 15 growth rings was last caught in 2009, making it a minimum of 41 years old at that time. An adult female first marked when it had 12 growth rings was last caught in 2008, making it at least 37 years old at that point. Both of these turtles could still be alive, as the recapture rate at this site is very low, given the low survey intensity. For example, the adult female caught in 2017 had not previously been captured since 2007. In total, 10 Spotted Turtles first marked in 1983 were at least 30 years old at last capture. This study provides additional evidence that Spotted Turtles are long lived and suggests that conservation efforts should focus on reducing mortality rates of adults.

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Sex-biased seasonal capture rates in Painted Turtle (*Chrysemys picta*)

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Abstract

We examined captures of Painted Turtle (*Chrysemys picta*) in Algonquin Provincial Park, Ontario, Canada, during the understudied summer–autumn transition period (August–September). The proportion of captured male turtles increased relative to the proportion of females during the late summer and early autumn sampling period, leading to male-biased capture rates in a population with a strongly female-biased sex ratio. We consider explanations for the capture bias in relation to sex-specific activity patterns and briefly discuss the implications of sampling period on the outcome of population structure studies.

Key words: Activity patterns; breeding; capture; *Chrysemys picta*; mating; Painted Turtle; seasonality; sex ratio; population studies; Algonquin Park

Introduction

Painted Turtle (*Chrysemys picta*) is among the most-studied freshwater turtles of North America (Lovich and Ennen 2013). The species' wide longitudinal and latitudinal geographic range (Hecnar 1999; Ernst and Lovich 2009) and relative abundance have supported a large volume of ecological, life history, and population biology studies (e.g., Wilbur 1975; Zweifel 1989; Congdon *et al.* 2003; Browne and Hecnar 2007; Lovich and Ennen 2013).

Much research on Painted Turtle biology has focussed on its active season, which extends from approximately May through August, depending on local regional climate. The overwintering period has also been subject to considerable study, given the unique physiological adaptations of adult and hatchling Painted Turtles to low dissolved oxygen and cold temperatures (Storey *et al.* 1988; Crocker *et al.* 2000; Costanzo *et al.* 2004; Rollinson *et al.* 2008). In contrast, research on Painted Turtle during the transition period between active season and overwintering has been largely neglected. Using observational study of Painted Turtles in Algonquin Provincial Park, south-central Ontario, we report on sex-biased captures during the understudied summer–autumn transition period and consider explanations for the bias in relation to sex-specific activity patterns.

Methods

Research on the biology of Painted Turtles at the Algonquin Wildlife Research Station, near the species' northern range limit, has been ongoing since 1978 under the leadership of R.J.B. and J.D.L. Observational and experimental study on the mating system of Painted

Turtles took place during late summer and early autumn 2013 (Moldowan 2014). Aquatic transects at Wolf Howl Pond (45°34'N, 78°41'W), Algonquin Provincial Park, were surveyed by canoe, and turtles were captured by hand and dip net. Between 10 and 44 Painted Turtles (mean = 24) were captured on 19 sampling occasions between 8 August and 24 September 2013 (Julian dates 220 through 267). Sampling was conducted between 1000 and 1600 on clear days with little wind. All observed individuals, regardless of activity (e.g., basking, free swimming, bottom walking), were targeted for capture.

Following capture, the sex of the turtles was recorded based on the presence or absence of sexually dimorphic characters (foreclaw elongation, carapace height, body size, and head shape morphology; Ernst and Lovich 2009; Moldowan *et al.* 2016, 2017). Individuals were counted only once during each sampling occasion. All captured individuals were marked members of the long-term study.

The population under study has a sex ratio of 0.29:1 male:female (Samson 2003; R.J.B. and J.D.L. unpubl. data). To test for a shift in sex ratio during the summer–autumn transition period, we conducted a linear regression analysis with Julian date as the predictor variable and sex ratio as the response variable. We also conducted a χ^2 test to verify that the sex ratio of turtles sampled in this study was reflective of the population sex ratio at large. Finally, linear regression was used to test whether sample size (predictor) affected sex ratio (response) among the captured turtles across all 19 sampling occasions. Findings were considered statistically significant at $\alpha < 0.05$.

Results

The proportion of captured male Painted Turtles significantly increased relative to the proportion of captured females during the late summer and early autumn sampling period (Figure 1). Painted Turtles captured during the summer–autumn transition period demonstrated a significant increase in male:female sex ratio ($R^2 = 0.60$, $F_{1,17} = 24.74$, $P < 0.001$), ranging by nearly an order of magnitude from 0.12 to 1.10 (Figure 2). The sex ratio of all turtles captured or recaptured across the 48-day sampling period was 0.39 male:1 female (129 male and 334 female captures/recaptures) and did not differ statistically from the expected ratio (i.e., the population sex ratio; Samson 2003; R.J.B. and J.D.L. unpubl. data) of 0.29:1 ($\chi^2_1 = 0.45$, $P = 0.57$). Size of the captured sample was not a significant predictor of sex ratio ($R^2 = 0.02$, $F_{1,17} = 0.33$, $P = 0.58$).

Discussion

Our seasonal capture records indicate differences in activity levels between male and female Painted Turtles during the summer–autumn transition period. Male Painted Turtles remain active later in the year than females. These observations are consistent with seasonally male-biased activity in Pond Slider (*Trachemys scripta*; Morreale *et al.* 1984; Thomas *et al.* 1999), Snapping Turtle (*Chelydra serpentina*; Brown and Brooks 1993), and a Virginia population of Painted Tur-

tles (Mitchell 1988). Morreale *et al.* (1984) and Thomas *et al.* (1999) have hypothesized that by extending the length of their active season, males can increase mate-searching activities, improve their chances of mating, and thereby potentially increase their reproductive fitness.

Across its range, Painted Turtle has two breeding periods, one at the beginning (spring) and one at the end (late summer and autumn) of the active season (Sexton 1959; Gibbons 1968; Ernst 1971a,b; Moll 1973; Licht *et al.* 1985; Gist *et al.* 1990; Ernst and Lovich 2009). Temperature (Ernst 1971a; Ganzhorn and Licht 1983; Licht and Porter 1985) and/or photoperiod (Mendonça 1987; Thomas *et al.* 1999) serve as the proximate mechanism(s) triggering the onset of reproductive cycling in temperate turtles. Across the geographic range of Painted Turtle, a gradient in the timing of reproductive activity is expected because of latitudinal differences in the length of the active season (Christiansen and Moll 1973; Moll 1973; Thomas *et al.* 1999). In Algonquin Provincial Park, the active (growing) season for ectothermic vertebrates is short, with an average of 115–125 frost-free days per year (OMAFRA 2013). Thermal and energetic constraints imposed by a northern climate on reproduction (Koper and Brooks 2000; Rollinson and Brooks 2007, 2008) may force female Painted Turtles to reduce the duration of their active season relative to that of males to conserve energy. Late summer and early autumn (August–Septem-

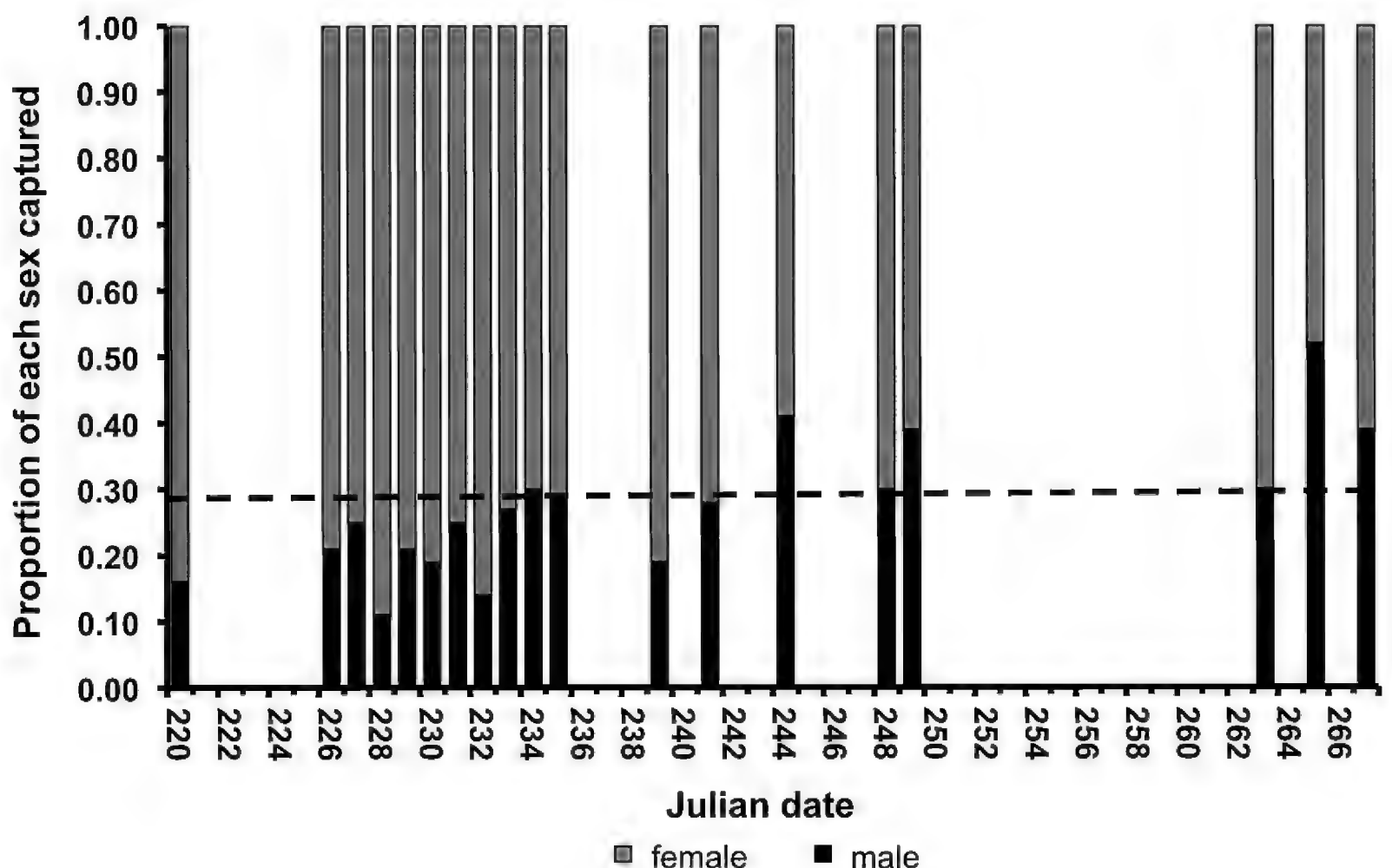


FIGURE 1. Proportion of captured Painted Turtles (*Chrysemys picta*) by sex during late summer and early autumn (8 August to 24 September 2013) in Algonquin Provincial Park, Ontario, Canada. The dashed line represents the expected proportion of males to females (0.29:1) based on the population sex ratio (Samson 2003; R.J.B. and J.D.L. unpubl. data).

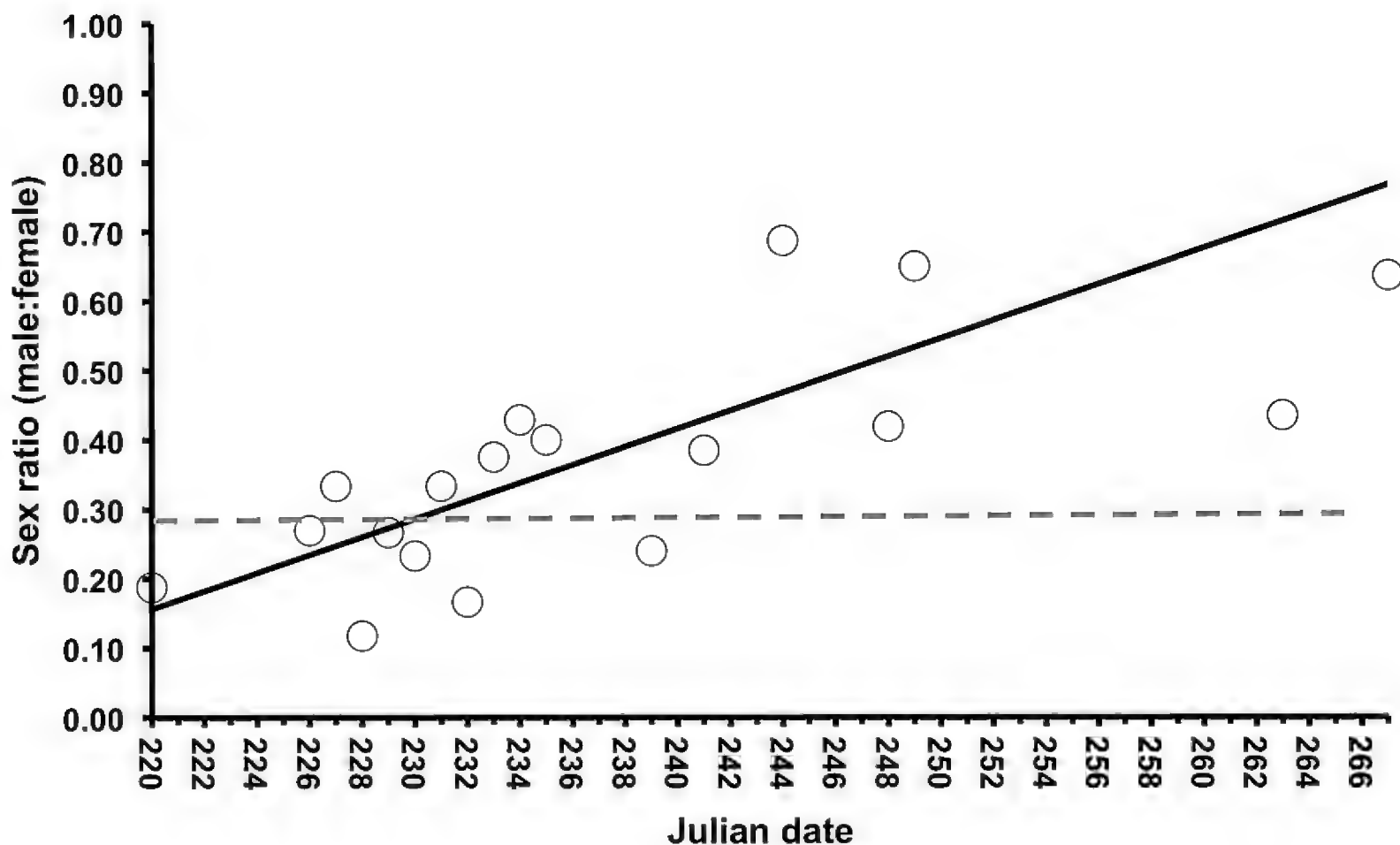


FIGURE 2. Increasing male bias in the sex ratio of captured Painted Turtles (*Chrysemys picta*) in Algonquin Provincial Park, Ontario, Canada, during the late summer–early autumn transition period, 8 August to 24 September 2013 ($y = 0.013x - 2.6926$, $R^2 = 0.60$). The dashed line represents the population sex ratio 0.29:1, male:female (Samson 2003; R.J.B. and J.D.L. unpubl. data).

ber) are energetically taxing times, as female Painted Turtles invest in follicular growth (Gibbons 1968; Congdon and Tinkle 1982; Mitchell 1985; Rollinson and Brooks 2007). Concurrently, male Painted Turtles undergo an increase in testis size from July to September (Gibbons 1968; Moll 1973; Congdon and Tinkle 1982) and an apparent increase in reproductive behaviour relative to females. Despite a reduction in female activity during summer–autumn transition, males may still secure mating opportunities by adopting coercive reproductive tactics (Moldowan 2014). Long-term sperm storage in Painted Turtle promotes multiple mating opportunities throughout the year and can lead to high reproductive success among males that successfully mate (Pearse *et al.* 2002; McGuire *et al.* 2011, 2014).

Our findings highlight the fact that sampling period can have considerable influence on measures of population structure (e.g., sex ratio) of Painted Turtle because of sex-specific activity patterns (Ernst 1971c; Mitchell 1988). Thus, those conducting demographic studies must be aware of sampling biases imposed by time of year. It is unlikely that our observed shift in male and female catchability is simply an artefact of sampling method (Ream and Ream 1966; Koper and Brooks 1998) because we used a consistent capture method over a relatively short sampling period, and our sample size did not affect sex ratio. Furthermore, our study site has been sampled annually for decades, with sampling occurring over many consecutive weeks dur-

ing spring population inventories (May) and nest monitoring (June), making it unlikely that turtles became exceptionally wary or demonstrated avoidance behaviour during autumn sampling. An increasing frequency of male conspicuousness (Figures 1 and 2) and reproductive activity (Moldowan 2014) provide evidence that late summer and early autumn is an important breeding period in this northern population of Painted Turtles.

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Body temperature influences growth rates of Common Gartersnakes (*Thamnophis sirtalis*)

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Abstract

Habitat selection can have large impacts on animal fitness. Temperature is an important aspect of habitat suitability for ectotherms, and temperature differences between habitats can thus lead to fitness differences. Here, we use an experiment with female Common Gartersnakes (*Thamnophis sirtalis*) to examine the effect of body temperature on change in mass (i.e., growth rate), which is a component of fitness. We placed female gartersnakes in experimental enclosures in old field and in forest and monitored their body temperature and mass throughout the summer. Gartersnakes in old field were warmer than gartersnakes in forest, warmer gartersnakes were more likely to eat earthworms, and warmer gartersnakes gained more mass. We therefore provide evidence that habitat use influences body temperature, and body temperature then influences growth, a component of fitness.

Key words: Common Gartersnake; *Thamnophis sirtalis*; body temperature; fitness; growth rate; habitat; thermoregulation

Introduction

Habitat selection is a major theme in ecology (Morris 2003). An individual's choice of where to live can have profound effects that ripple throughout its life, from immediate effects on safety (Dupuch *et al.* 2009), food availability (Morris and MacEachern 2010), and physiology (Halliday and Blouin-Demers 2014), to fecundity and population level consequences (Lin and Batzli 2001). Habitats can be simply defined as "... subsets of physical and biotic conditions among which population density ... of a focal species varies from adjacent subsets" (Morris 2003: 2). Habitats therefore are often defined by their impact on fitness, which highlights the importance of understanding how different abiotic and biotic conditions impact fitness.

For ectotherms, temperature is one of the most important variables in habitat selection (Huey 1991) because they, by definition, rely on environmental temperature (T_e) to maintain their body temperature (T_b), and in turn T_b greatly impacts fitness (Gilchrist 1995). Fitness typically is maximized at some optimal temperature (T_o), and decreases as temperature deviates from T_o (Bulté and Blouin-Demers 2006; Dell *et al.* 2011). Ectotherms that maximize fitness should therefore select habitats that allow them to maintain T_b as close to T_o as possible (Blouin-Demers and Weatherhead 2008).

In our previous work with Common Gartersnakes (*Thamnophis sirtalis*), we demonstrated that they selected warm fields over cool forest, and that selection of old field habitat led to higher growth rate and repro-

ductive success (Halliday and Blouin-Demers 2016a). Despite this correlation, we did not demonstrate explicitly that warmer snakes exhibited higher growth rates. Here, we re-examine these data to explore the relationship between weekly T_b and changes in mass for individual snakes in experimental enclosures in field and forest. We directly test the prediction that warmer snakes have higher growth in mass than cooler snakes, independent of their habitat.

Methods

In June 2014, we built six experimental enclosures in an old field and six enclosures in an adjacent forest (individual dimensions [$l \times w \times h$] = $2.67 \times 2.67 \times 1.3$ m) in Pontiac county, Quebec (45.4926°N, 75.9222°W). We built the frames of the enclosures with lumber and stapled polyethylene sheeting to the wood frame to create walls. We buried the walls in the ground at least 10 cm to prevent snakes from escaping. We placed fine mesh over the enclosures to exclude birds, and electric fences around the enclosures to exclude mammalian predators. We placed a plywood board (60 × 60 cm) in each enclosure to act as a refuge. The old field was a mix of grasses and flowering plants, including goldenrod (*Solidago* sp.), milkweed (*Asclepias* sp.), and Tufted Vetch (*Vicia cracca* L.). The forest consisted mostly of Trembling Aspen (*Populus tremuloides* Michaux) with minimal understorey growth.

We captured adult female gartersnakes between late April and early June 2014 near a wetland within 10 km

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of our experimental enclosures and placed 10 individuals in the old field enclosures and 10 in the forest enclosures, with two individuals per enclosure in four of the enclosures in each habitat and one individual per enclosure in two of the enclosures in each habitat. We used gravid females because the main goal of this experiment was to examine the fitness consequences of habitat selection, therefore we measured reproductive output (Halliday and Blouin-Demers 2016a). We randomly assigned females to habitats and enclosures, while ensuring that the body size distribution was similar between habitats. We also randomly assigned half of the females in each habitat to a “low food” treatment, and the other half to a “high food” treatment. In the low food treatment, we offered each female one large earthworm twice per week and in the high food treatment we offered each female one large earthworm four times per week. We offered earthworms to snakes by isolating the snake within its enclosures and dropping an earthworm in front of its head. This typically elicited a feeding response, whereby the snake immediately struck the earthworm or began flicking its tongue at the worm. We recorded whether the snake ate the earthworm. Snakes also had access to food naturally available in the enclosures, so our food treatments represent food supplementation.

Prior to feeding, we measured the skin temperature of each snake with an infrared thermometer (Fluke 566 infrared thermometer, Fluke Corporation, Everett, Washington, USA); skin temperature is highly correlated with internal body temperature in gartersnakes (Spearman's $\rho \geq 0.87$; Halliday and Blouin-Demers 2017a). We held the thermometer 10 cm from the snakes and aimed at the centre of their bodies. We recorded whether the snake was out and basking or whether it was under the cover board. We measured T_b four times per week at 0900. Once per week, we measured the mass of each snake with a spring scale (Pesola AG, Schindellegi, Switzerland). We continued this experiment until the beginning of September (105 days), which was the point when all gravid females had given birth. We include measurements for each female only until the week before it gave birth. By the end of this experiment, the final sample size was six gartersnakes in each habitat; however, we collected sufficient data from all 10 snakes in each habitat to include data from all 20 snakes in the analyses. The loss of snakes was due to escapes and predation.

Analyses

We first conducted a t -test to verify that females in each habitat had similar starting masses. We then conducted an analysis to describe the difference in T_b between habitats. We used a linear mixed effects model in R (package lme4; function lmer; Bates *et al.* 2015) with daily T_b of each individual snake as the dependent variable, combinations of food treatment, habitat, the snake's location (i.e., under cover, out of cover), and all two-way interactions as fixed effects, and with

snake ID as a random effect. We compared models with Akaike's information criterion (package stats; function AIC; R Core Team 2016) and selected the model with the lowest AIC as the best model. If models were within 2 AIC units of the best model, we considered them to be competing and used the most parsimonious of the competing models as the final model.

For our second analysis, we examined whether a snake ate during a given feeding event using general linear mixed effects models with a binomial distribution (package lme4; function glmer; family: binomial). We used the occurrence/non-occurrence of a feeding event (where 1 = the snake ate the worm and 0 = the snake refused the worm) as the dependent variable and temperature, location, food treatment, habitat, and two-way interactions as fixed effects, and snake ID as a random effect.

For our final analysis, we examined the change in mass for a snake from one week to the next with linear mixed effects models, with change in mass as the dependent variable and combinations of the following independent variables as fixed effects, including two-way interactions: habitat, food treatment, mean temperature over the previous week, and days since the last food item was eaten. We included snake ID as a random effect.

Results

At the beginning of the experiment, females in field and forest habitat ($n = 10$ in each habitat) did not differ significantly in mass (mean \pm SE in field: 72.0 ± 9.9 g, in forest: 72.8 ± 11.8 g; $t = 0.05$, $P = 0.96$).

On average, the T_b of gartersnakes was lower in forest than in field (mean difference = $4.6 \pm 0.4^\circ\text{C}$, $t_{720} = 12.33$, $P < 0.01$; Figure 1; Appendix S1). Individuals under cover were cooler than individuals out of cover, especially for snakes in the forest ($t_{720} = 5.45$, $P < 0.01$) or in the low food treatment ($t_{720} = 2.04$, $P = 0.04$).

Gartersnakes were more likely to eat if their T_b was higher (effect size = 0.10 ± 0.03 , $t_{564} = 3.76$, $P < 0.01$; Appendix S2), if they were in the low food treatment (effect size = 1.68 ± 0.47 , $t_{564} = 3.58$, $P < 0.01$), and if they were in the field (effect size = 1.05 ± 0.47 , $t_{564} = 2.23$, $P < 0.01$). All interaction terms in this model were non-significant (Appendix S2).

Regardless of habitat or food treatment, gartersnakes were more likely to gain mass from one week to the next if their mean T_b was higher in the previous week (slope = 0.26 ± 0.11 , $t_{174} = 2.24$, $P = 0.03$; Figure 2; Appendix S3). All interaction terms in this model were non-significant (Appendix S3).

Discussion

Habitat selection by ectotherms influences T_b , which in turn influences fitness because of the direct link between T_b and fitness (Blouin-Demers and Weatherhead 2008). In this study, we demonstrate that gartersnakes in our field enclosures had a higher T_b than gartersnakes

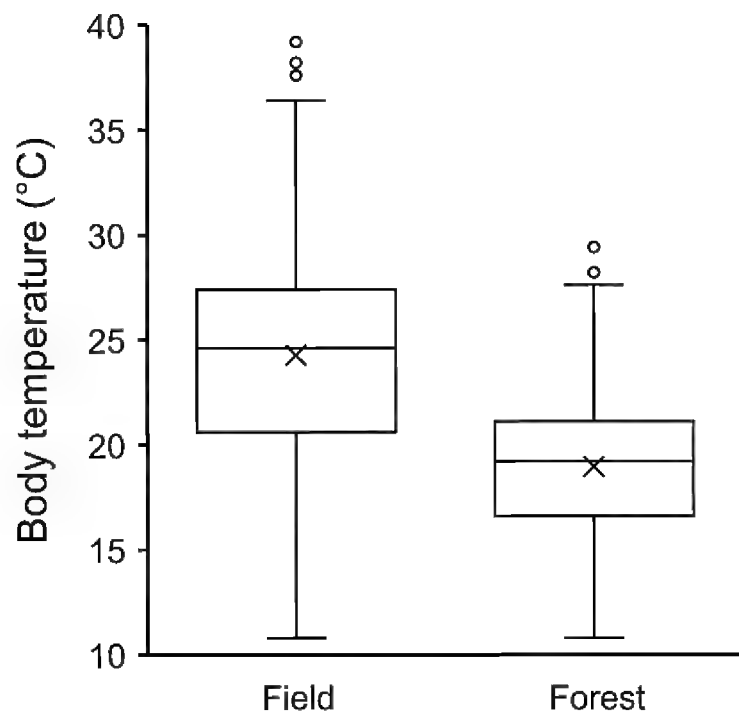


FIGURE 1. Body temperature of female Common Gartersnakes (*Thamnophis sirtalis*) living in enclosures in old field and forest habitat in Pontiac county, Quebec between June and September 2014. Boxes represent the interquartile range, lines within the box are the median, 'x' in the box is the mean, whiskers are the 5th and 95th percentiles, and points above the whiskers are outliers. $n = 726$ temperature measurements on 20 individual gartersnakes.

in forest enclosures, and that gartersnakes with higher T_b are more likely to eat and have a greater mass increase regardless of habitat or food treatment. We previously demonstrated that T_e was higher in field than in forest (Halliday and Blouin-Demers 2016a) and here we demonstrate that this increased T_e translated to increased T_b . We also previously demonstrated that gartersnakes are more willing to eat at temperatures closer to their preferred T_b in the laboratory (Halliday and Blouin-Demers 2016b) and here we extend this finding to the wild; we found that gartersnakes are more likely to eat when they are warmer and that warmer gartersnakes grow more or produce larger offspring. We therefore provide direct evidence that habitat use dictates T_b , which then influences growth rate, a component of fitness.

Other studies of ectotherm habitat selection have indicated a strong preference for the habitat that most closely matched optimal temperature (Huey 1991; Calsbeek and Sinervo 2002; Halliday and Blouin-Demers 2014; Paterson and Blouin-Demers 2018). Similarly, several studies have demonstrated the link between temperature and growth rate in ectotherms (Bronikowski 2000; Patterson *et al.* 2017). Our study extends the findings of these previous studies by demonstrating that short-term changes in body temperature (over one week) can lead to changes in growth, and therefore influence fitness.

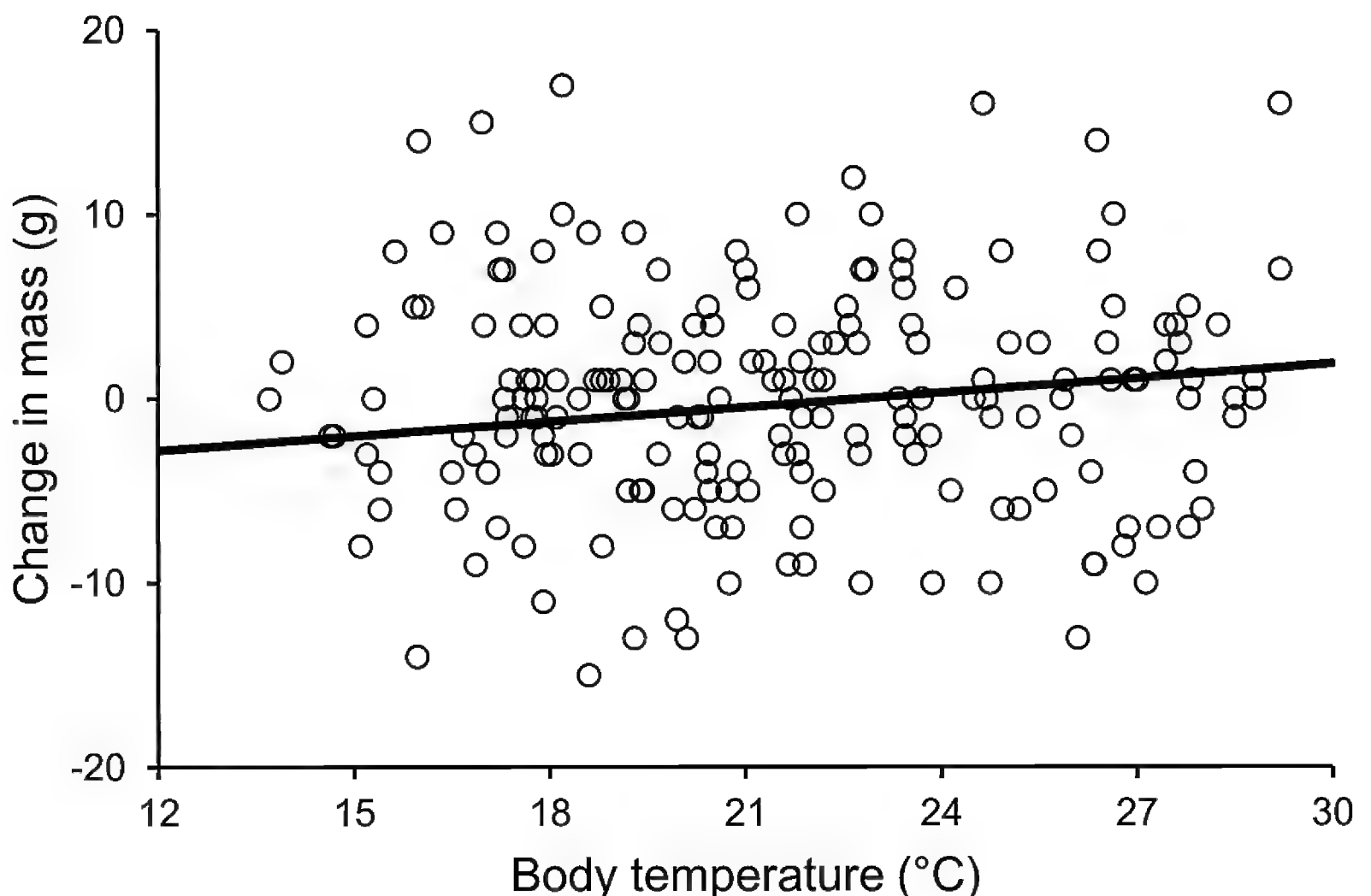


FIGURE 2. The relationship between mean body temperature in the previous week and change in mass for female Common Gartersnakes (*Thamnophis sirtalis*) living in enclosures in old field and forest habitat in Pontiac county, Quebec between June and September 2014. The line represents the relationship between body temperature and change in mass, according to a linear mixed effects model. $n = 195$ change in mass measurements on 20 individual gartersnakes.

Although willingness to eat and growth were both related to T_b , the number of worms eaten did not affect growth, and neither did the food treatment we imposed. This is likely due to an abundance of naturally available worms within our enclosures, which we could not control or account for. In another experiment with similar enclosures, we monitored worm abundance and caught worms throughout the course of our study (Halliday and Blouin-Demers 2017b). In that experiment, worm abundance was on average lower in enclosures with more snakes, which suggests that snakes were eating the worms that entered the enclosures. The worms that we fed to the snakes were an additional meal, but likely did not provide enough additional energy to affect growth detectably. The feeding treatments therefore provide evidence of the link between T_b and foraging but cannot directly link foraging and growth, even though it is logical that individuals that eat more worms should grow more. To test the link between T_b , foraging, and growth effectively one would need to completely control the food intake of study organisms, which is challenging under field conditions. While our field enclosures did not allow us to control food intake and were not entirely escape or predator proof, enclosures do offer natural habitat conditions, including natural variation in temperature and insolation, that increase the ecological realism compared to laboratory studies. Given that the main goal of our experiment was to examine the effect of habitat and temperature on fitness, we feel that field enclosures were more appropriate than more controlled laboratory conditions. Captivity stress is also likely to be lower in field enclosures than in the laboratory.

We used gravid females in our experiment complicating the interpretation of our results. Unlike juveniles, adult males, and non-gravid females, energy intake by gravid females is not only self-directed but also to the developing offspring. We use the term growth rate, but changes in mass are likely happening in both the offspring and in the females. In our previous analysis of this experiment (Halliday and Blouin-Demers 2016a), we demonstrated that females also grew in length, which implies that at least some of the change in mass is directly related to growth of the females and not just to growth of the offspring. Another potential issue associated with using gravid females in this experiment is that they often fast during pregnancy (e.g., Lourdaïs *et al.* 2002), which has obvious implications for a growth rate study. But this was not the case in our study: all females ate, especially if their body temperature was high.

The effect of T_b on growth was relatively weak (slope = 0.26 g/°C), probably because we measured T_b only four times each week. There was likely greater variation in snake T_b that we did not capture. We measured T_b at the same time every day, so we did not capture daily variation in T_b . A larger sample size with more continuous T_b measurements would likely lead to a stronger relationship between T_b and growth.

In summary, our study demonstrates the link between habitat use and growth, a component of fitness, via the temperature-dependence of foraging and growth. Studies on ectotherms, and to a lesser extent on endotherms, must consider temperature as an important habitat feature that can influence behaviour, physiology, and ultimately fitness.

Author Contributions

Writing – Original Draft: W.H.; Writing – Review & Editing: W.H. and G.B.-D.; Conceptualization: W.H. and G.B.-D.; Investigation: W.H.; Methodology: W.H.; Formal Analysis: W.H.; Funding Acquisition: W.H. and G.B.-D.

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SUPPLEMENTARY MATERIAL:

APPENDIX S1: Model selection and final model output for an analysis of the effect of Common Gartersnake (*Thamnophis sirtalis*) body temperature on growth.

APPENDIX S2: Model selection and model final output for an analysis of feeding behaviour of Common Gartersnakes (*Thamnophis sirtalis*).

APPENDIX S3: Model selection and final model output for an analysis examining the growth of Common Gartersnakes (*Thamnophis sirtalis*).

Snake mortality and cover board effectiveness along exclusion fencing in British Columbia, Canada

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Abstract

We report on snake mortalities along exclusion fencing in southern British Columbia, showing Western Yellow-bellied Racer (*Coluber constrictor mormon*) deaths were disproportionately higher than our encounter rates with the species within the snake community. This suggests racers were susceptible to fence mortality more so than Northern Pacific Rattlesnakes (*Crotalus o. oreganus*) or Great Basin Gophersnakes (*Pituophis catenifer deserticola*). Datalogger recordings revealed temperatures under cover boards were well above the tolerable temperatures of the three snake species, although the boards appeared to temper ambient heat more efficiently than natural vegetation. We caution that the effects of fencing and cover boards may vary across ecosystems and snake species.

Key words: *Coluber*; conservation; *Crotalus*; Great Basin Gophersnake; Northern Pacific Rattlesnake; *Pituophis*; reptiles; Western Yellow-bellied Racer

Introduction

Human disturbance imposes drastic changes upon natural environments, often with severe consequences for wildlife populations. Two such effects are barriers to movement, and increasing human-wildlife interactions (Colley *et al.* 2017; Markle *et al.* 2017; Pitts *et al.* 2017). Managers often employ multiple techniques to mitigate negative human-wildlife conflicts. Historically, wildlife fencing is considered an efficient approach for limiting wildlife movement. Most notably, it has been used to reduce road mortality of large macrofauna (Peaden *et al.* 2017) but has also been widely used for herpetofauna (Colley *et al.* 2017; Markle *et al.* 2017).

In general, there are two major fence types used to direct the movements of herpetofauna: drift and exclusion. Drift fences are long continuous barriers used to channel animal movement, often for research purposes by adapting them to trap animals (Willson and Gibbons 2009). Conversely, exclusion fences eliminate animal access to a specific area such as roadways and areas with high human influence (Markle *et al.* 2017).

Exclusion fencing can be an important conservation tool to promote spatial separation between humans and animals that pose a risk, such as venomous snakes. Historical efforts to limit and manage negative snake-human

interactions often have included the relocation of animals. However, this strategy has limitations and potential negative consequences on the translocated snakes (Reinert and Rupert 1999; Nowak *et al.* 2002; Brown *et al.* 2009). More recently, fencing has been used to target snakes and other reptiles to limit road mortality and restrict animal movement through various urban settings (Colley *et al.* 2017; Markle *et al.* 2017).

Although sometimes effective, wildlife fences pose potential problems to snakes and other reptiles such as restricting movements or otherwise altering behaviour (Markle *et al.* 2017; Peaden *et al.* 2017). For example, Mohave Desert Tortoises (*Gopherus agassizii*) that encountered roadside fencing had extreme carapace temperatures that approached the species' tolerance limits and exhibited greater movement velocity compared to individuals away from fencing structures (Peaden *et al.* 2017). Furthermore, Wilson and Topham (2009) found that fencing caused road mortality by preventing Tiger Whiptail lizards (*Aspidoscelis tigris*) from retreating from the danger posed by roads. In Australia, Eastern Long-necked Turtle (*Chelodina longicollis*) mortalities (mainly due to overheating) were observed along a pest-exclusion fence, with animals showing signs of sunburn and predation (Ferronato *et al.* 2014). Despite

these examples of varying fence effects, the potential direct and indirect negative effects that fencing has on herpetofauna is still largely unknown and understudied, particularly for snakes.

Here we outline observations on the impacts of mitigative exclusion fencing on a snake community in arid southern British Columbia. We compare observations and counts of live and dead snakes detected near the fence, and also report on the use of wooden cover boards as putative thermal refugia for snakes moving along the fencing structure in the hot, open desert habitat.

Methods

Our study site was located on the Osoyoos Indian Reserve (OIR) near the town of Osoyoos (49.03°N, 119.47°W) in the south Okanagan Valley of British Columbia (BC). The 450 ha study area contains a dry, arid ecosystem composed of shrub-steppe habitat dominated by Antelope-brush (*Purshia tridentata* (Pursh) de Candolle) and Big Sagebrush (*Artemisia tridentata* Nuttall). Mean summer (June, July, August) air temperature in Osoyoos and surrounding south Okanagan Valley is approximately 22°C. However, summer mean maximum temperatures can be as high as 33°C and extreme maximum temperatures will exceed 40°C (Environment Canada 2017), making this one of Canada's hottest regions. The study site has been, and continues to be, heavily altered as the landscape shifts towards tourism development including golf courses, vineyards, a resort and campground, and associated roads and parking lots. The study site is home to a long-term snake research project targeting three species-at-risk, Northern Pacific Rattlesnake (*Crotalus o. oreganus*), Great Basin Gophersnake (*Pituophis catenifer deserticola*), and Western Yellow-bellied Racer (*Coluber constrictor mormon*). Both this rattlesnake and gophersnake are listed as threatened species in Canada (SARA Registry 2018a,b) and the racer has been recommended for listing as threatened (COSEWIC 2015). For additional description of the region and the study site, see Brown *et al.* (2009) and Lomas *et al.* (2015).

In an attempt to mitigate negative human-snake conflict, ~4 km of exclusion fencing was built in 2006 to separate natural snake habitat from the high human traffic and popular tourist areas. The fence was constructed of ~60 cm high galvanized mesh hardware cloth with ~0.60 cm square openings and ran approximately north-south through the study area. In 2006, during initial construction of the fence, snake mortalities were observed along a newly constructed section of the fence (one neonate rattlesnake and six racers; O.M.M. pers. obs.). These early observations suggested that snakes may have been dying from exposure to daytime heat while attempting to navigate the new physical barrier.

In 2007 we investigated if the construction of artificial cover, in the form of wooden cover boards, would

create appropriate thermal refuge habitat for snakes moving along the new fence structure. Twelve sets of triplet plywood cover boards (70 cm × 70 cm × 7 cm) were placed along the exclusion fence at 30 m intervals (equalling 360 m of the fencing structure), in the area where snake mortalities had been observed the previous year. At each interval, two of the three boards were placed on opposite sides of the fence and the third board was placed 10–15 m east of the fence in the natural habitat as a control. Each cover board was raised approximately 7 cm off the ground by wooden edge pieces, and 15–20 cm of sand was excavated under the centre of each board to ensure access for both large and small reptiles.

Dataloggers (DS1921G Thermochron® iButton®; Baulkham Hills, New South Wales, Australia) were used to record temperature data every hour between May and October 2007. The dataloggers were placed under fence ($n = 10$) and control ($n = 6$) cover boards, and under natural vegetation typically favoured by snakes (Big Sagebrush, Rubber Rabbitbrush [*Ericameria nauseosa* (Pallas ex Pursh) G.L. Nesom & G.I. Baird], Antelope-brush; $n = 5$). We placed an additional datalogger fully exposed on the open ground to collect additional reference data. Furthermore, throughout the course of the 2007 summer field season, we monitored and observed the cover boards for snake use. We compared the average maximum daily temperature (typically 1400–1600 h) between the different treatments throughout July 2007. We chose to focus on July because it typically constitutes the hottest month of the active season in the Okanagan Valley (Environment Canada 2017) when refuge from the heat would be critical.

In 2015, major upgrades along the fence were performed, including repair work, vegetation control, and re-routing approximately 200 m to avoid erosion. This marked the first major, large-scale upgrade to the entire fence structure since its original construction. Over the next two years (2016–2017), fence surveys (walking fence line) were initiated approximately 2–3 times a week between May and October to detect snakes and monitor fence effectiveness. In addition to the fence surveys, we conducted mark–recapture surveys almost daily (5–6 days per week) throughout the entire study area. We captured and marked live-snakes with Passive Integrated Transponders (PIT tags - HPT12 Pre-load; Biomark Inc., Boise, Idaho, USA) to allow for individual recognition in subsequent captures.

Results

Temperature differences between the fence cover boards and control cover boards appeared to stay relatively consistent throughout July, and cover boards had lower average maximum daily temperatures than the native vegetation cover or areas with no cover (Figure 1). Maximum daily temperatures during mid-summer (July) routinely surpassed 35°C at all of our

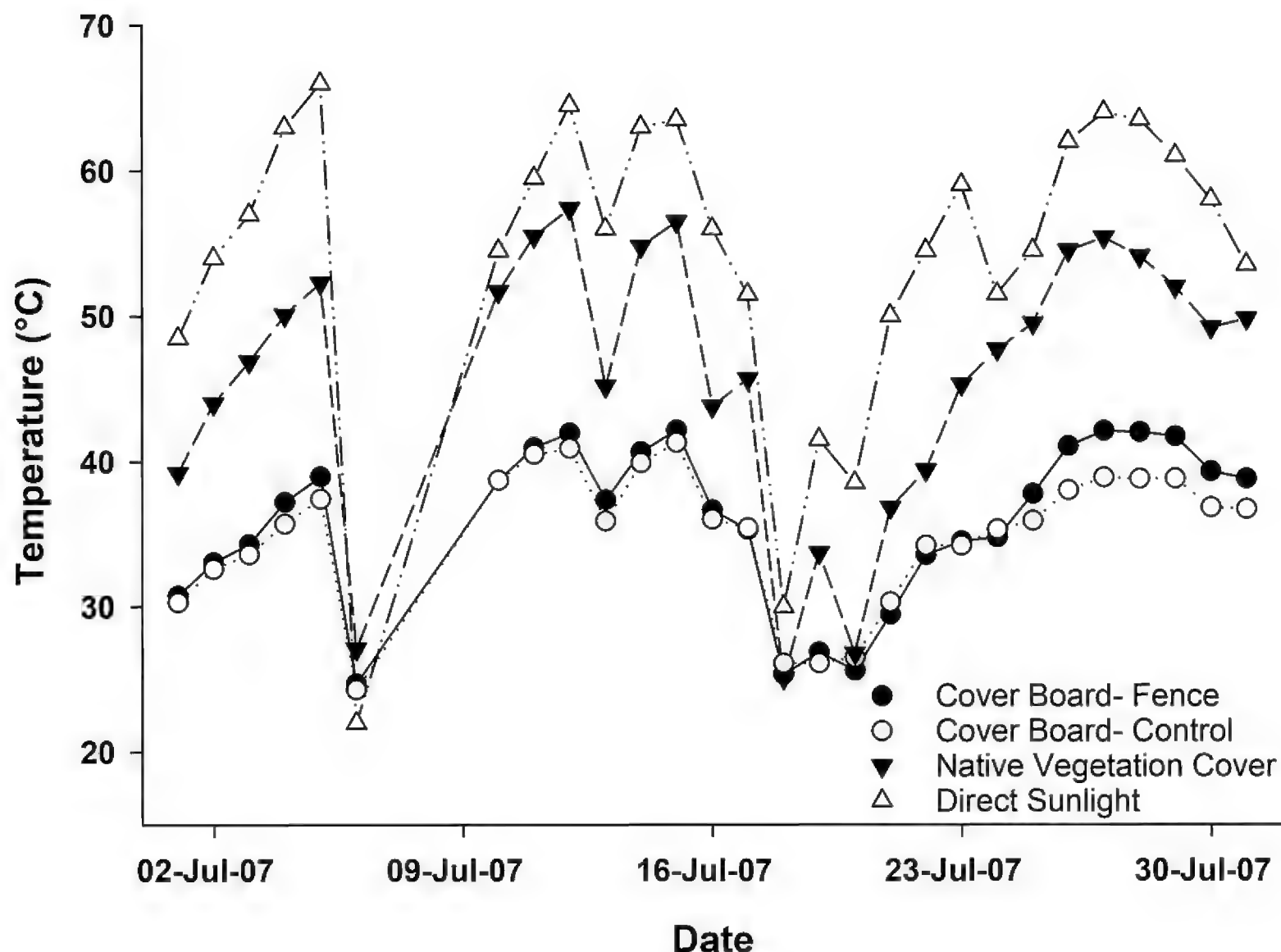


FIGURE 1. Daily mean maximum temperatures of fence ($n = 10$) and control ($n = 6$) cover boards, natural vegetation cover ($n = 5$) and exposed ground ($n = 1$) in July 2007 on the south Okanagan Valley study site, near Osoyoos, British Columbia.

recording sites (including under cover boards), and temperatures under native vegetation cover occurred in excess of 50°C. We found nine rattlesnakes under cover boards along the fence over the course of the entire 2007 active season.

During the 2016 and 2017 field seasons (following fence upgrading), 341 snakes were captured throughout the entire study area during ongoing mark-recapture and monitoring of the snake community. Specifically, counts of the three main species in the area were 215 rattlesnakes, 62 gophersnakes, and 64 racers. During this same time, we captured 116 live snakes (59 rattlesnakes; 23 gophersnakes; 34 racers; Figure 2) directly along the same section of fence earlier used for the cover board study; however, no snakes were captured under cover boards. We also observed 15 snake mortalities directly along the same fence section (two rattlesnakes; one gophersnake; 12 racers). Additionally, we found six of the 15 dead snakes (one rattlesnake, one gophersnake and four racers) within the section of fence that was added in 2015. We found all snake mortalities along the exclusion fence in the open rather than beneath cover boards. In total, fence mortalities appeared responsible for 33% (15/45) of snake mortality observations throughout our study site during the 2016 and

2017 field seasons (roadkill = 49%, unknown and/or natural mortality = 18%).

The relative proportions of the three snake species within the sample of fence captures differed significantly (R Core Team 2016) from recorded captures over the larger study area ($\chi^2_2 = 9.4$, $P < 0.01$). At the same time, the relative proportions of dead snakes observed along the fence differed significantly from both live snakes captured near the fence ($\chi^2_2 = 18.9$, $P < 0.01$) and from those in the general population ($\chi^2_2 = 36.3$, $P < 0.01$). In all cases, racers were over-represented in the fence mortality data set, and rattlesnakes under-represented (Figure 2).

Discussion

Although using cover boards to monitor snakes and other herpetofauna is a common and efficient practice (Reading 1997; Engelstoft and Ovaska 2000; Halliday and Blouin-Demers 2015), they appeared to be under-used by snakes in our study area, as we only observed nine rattlesnakes (no gophersnakes or racers) under cover boards during an entire active summer season. For snakes and other reptiles, thermal requirements while balancing predator avoidance are key drivers of microhabitat selection (Downes 2001; Lelièvre *et al.*

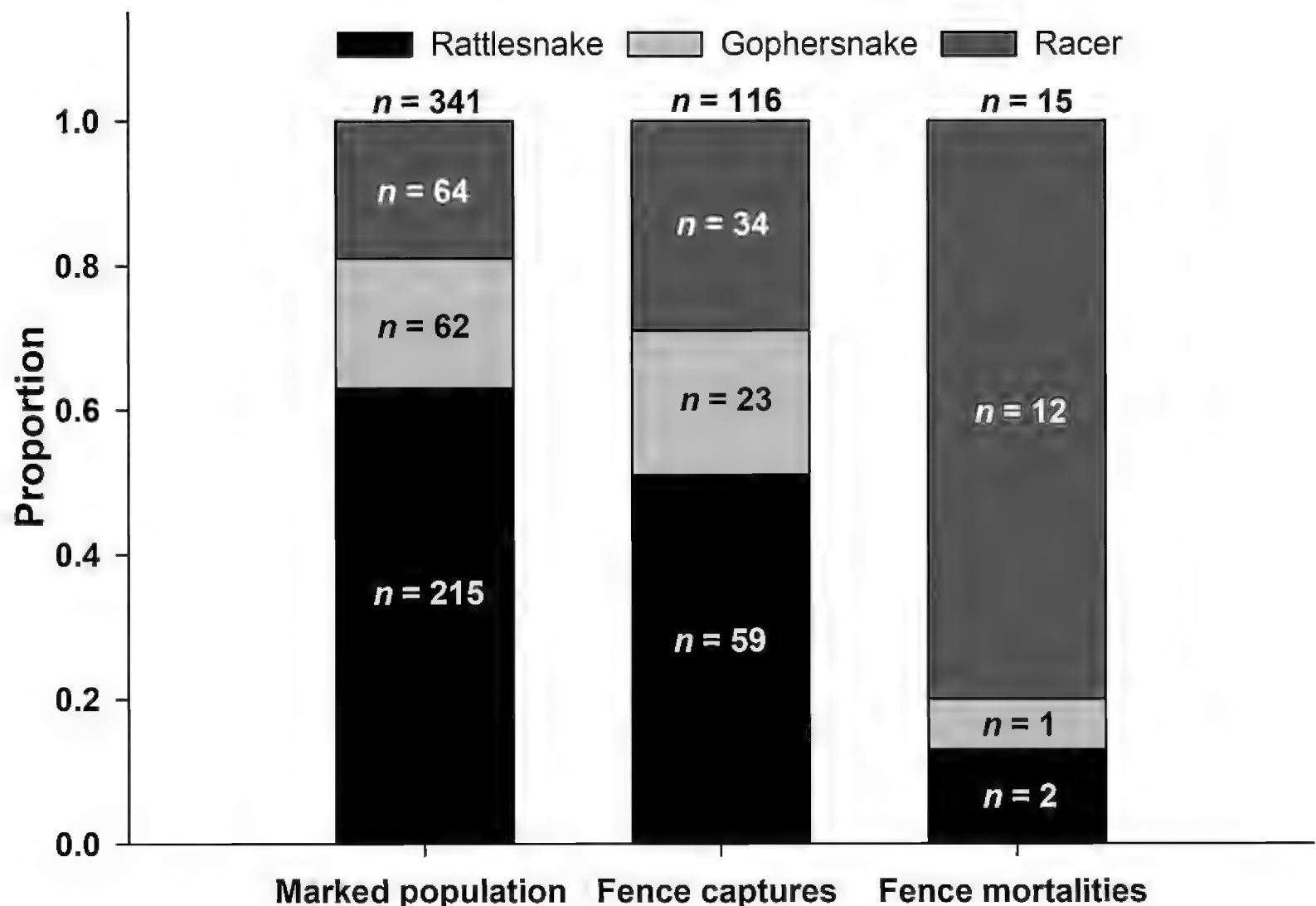


FIGURE 2. Total sample sizes and proportion comparisons of Northern Pacific Rattlesnake (*Crotalus o. oregonus*), Great Basin Gophersnake (*Pituophis catenifer deserticola*), and Western Yellow-bellied Racer (*Coluber constrictor mormon*) marked populations, fence captures, and fence mortality observations during the 2016 and 2017 field seasons at the south Okanagan Valley study site, near Osoyoos, British Columbia.

2010). Based on our capture rates, individual snakes appeared not to be using these cover board ‘habitats’ heavily during the peak summer season, likely because the high temperatures under the boards negated any benefit in terms of potential predator avoidance or thermal refuge. Average daily maximum temperatures during July under the cover boards were typically far higher than the preferred body temperatures and critical maxima reported for rattlesnakes (28.9°C versus 39–40°C), gophersnakes (26.7°C versus 40.5°C), and racers (28.3°C versus 42.4°C; Brattstrom 1965; Putman and Clark 2017; Figure 1). We acknowledge that operative body temperatures of snakes often may vary from ambient air temperature (Blouin-Demers and Weatherhead 2001), and direct comparisons between air temperature and preferred snake body temperature may be, in some cases, questionable. However, the degree to which our recordings surpassed the published tolerance levels for these snakes strongly suggests the boards would have represented inappropriate microhabitat.

In comparison, average daily maximum temperatures in July under the cover boards were cooler than those recorded under the local native vegetation. This may imply that effective refuge sites (e.g., large rock formations, deep holes) during the peak summer heat

may be critical, at least in this particular ecosystem. Modifications to these cover boards would appear necessary for creating suitable thermal refuge habitat for snakes during the height of summer at our study site. Examples of possible modifications include increasing the overall size of the plywood structure (Halliday and Blouin-Demers 2015), applying a coating to the outer surface of the cover board specifically to reflect solar radiation (Synnefa *et al.* 2005), and/or increasing the insulation under the cover boards through pits or underground chambers (C.A.B. and K.W.L. pers. obs.).

Racer mortalities along the fence were proportionally over-represented compared to our overall captures of snakes in the community, strongly suggesting these animals were predisposed to dying near the fence more so than the other two species. The impact of exclusion fencing may be greater for agile and highly active snakes. Species that are relatively active and/or undergo longer migrations may be more likely to encounter fences and other disturbances, potentially becoming isolated from crucial resources (Ferronato *et al.* 2014; Martin *et al.* 2017). Home range and movement data for Western Yellow-bellied Racer in BC are scant, but Brown and Parker (1976) showed home ranges for

this species in Utah generally extended no further than 1000 m from den sites. In the Okanagan Valley, the average maximum distance gophersnakes disperse from their dens is 520 m (10.5 ha home range: Williams *et al.* 2012) and rattlesnakes in our study area move an average of 1082 m (25.1 ha home range) from their den location (Brown *et al.* 2009). In the south Okanagan Valley, racers are considered the most diurnally-active species with higher levels of activity, exposure and heat tolerance than other species (Brattstrom 1965; Ernst and Barbour 1989; COSEWIC 2015). Possibly a predilection for movement during the daytime renders racers relatively vulnerable to overheating and other lethal effects experienced while navigating fences and other obstacles.

Sudden increased mortality during the 2016–2017 field seasons could be due to several factors, such as the lack of direct surveying in the past (monitoring is time consuming and requires many working hours), or it may be correlated with fence upgrades that rendered the structure more impermeable to snakes. The specific section of the fence where snake mortalities were observed runs parallel to a lake (to exclude snakes from a large campground), restricting access to riparian habitat for those seeking to rehydrate, hunt, and avoid periods of extreme heat.

Following the new 200-m addition to the fence, we detected relatively more dead snakes along that section than elsewhere in our study site. The six snakes (40% of fence mortalities) found dead within a 20–30 m section of the newly constructed section are of particular interest. These observations, along with the six dead snakes originally observed during initial fence construction in 2006, may suggest new exclusion fencing poses accentuated problems for snakes in the short term. However, without better knowledge on the factors driving snake migration and movements, it is difficult to determine why fencing and changes to fencing structures would increase mortality rates. Additionally, further investigation, long-term monitoring, and more detailed analysis are required to determine potential population-level impacts these fence mortalities are actually having in our study area.

Exclusion fencing has become a common strategy to mitigate human-reptile conflict and can be extremely effective; however, it is clear with our findings that the use of exclusion fencing is not without concern. The broader effects of exclusion fencing need to be investigated further to fully understand the implications and perhaps consequences to animals such as snakes. Similar to concerns raised for reptiles in other hot, dry regions (Ferronato *et al.* 2014; Peadar *et al.* 2017), there appears to be potential negative consequences for snakes encountering fencing in our study area.

Author Contributions

Writing – Original Draft Preparation: D.M.E. and J.R.M.; Writing – Review and Editing: D.M.E., J.R.M.,

K.W.L., and C.A.B.; Formal Analysis: D.M.E. and J.R.M.; Funding Acquisition: K.W.L. and C.A.B.; Investigation: D.M.E., J.R.M., and O.M.M.; Methodology: D.M.E., J.R.M., O.M.M., and K.W.L.; Supervision: K.W.L. and C.A.B.

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Factors affecting litter size in Western Gartersnake (*Thamnophis elegans*) in British Columbia: place, time, and size of mother

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Abstract

Life-history traits of organisms are influenced by both genetic and environmental factors. We used counts of offspring in captive-born litters to determine how geographic location, year-to-year variation, and body size of mother affected litter size of Western Gartersnake (*Thamnophis elegans*) in four widely separated populations in British Columbia. Litter size varied significantly among populations, but that variation was largely explained by differences in maternal body size among populations; that is, larger females had larger litters. With maternal size treated as a covariate, there was no further significant effect of location or of different years within sites on litter size. The overall regression, pooled over sites and years, between litter size and size of mother accounted for 55% of the total variation in litter size. Nonetheless, the significant variation in body size among locations calls for explanation and the consequent differences in litter size could be important demographically. Presumably, the large amount of unexplained residual variation reflects other differences, beyond body size, between individual mothers. Such differences among individuals might be determined by genetics or by environmental effects such as foraging success, but our data cannot address this question.

Key words: Gartersnake; *Thamnophis elegans*; British Columbia; litter size; body size

Introduction

Life histories are suites of co-varying traits that influence the dynamics of a population and therefore its potential rate of increase in numbers. Key life-history traits of animals include clutch/litter size and frequency, offspring size at hatching/birth, individual growth rate, body size, age at reproductive maturity, and mortality rate (Stearns 1992). Thus, the individual organism's life history is a measure of its relative fitness. To the extent that they are heritable, life histories, and the traits that comprise them, are subject to natural selection; different life histories may be advantageous in different situations (e.g., high versus low risk of predation; Reznick and Endler 1982; more versus less variable environments; Bronikowski and Arnold 1999).

Life histories vary among taxa at all taxonomic levels, including lineage-specific effects. For example, most lizards can vary their clutch size, but two unrelated lineages of lizards, geckos and anoles, have fixed clutch size of one or two eggs (Selcer 1990). Small fixed clutches appear to be adaptations to arboreal habitats in the tropics in which these two groups originated, but they may now constrain these lizards from colonizing temperate-zone environments (Ballinger 1983). Most life-history traits, however, are not constant, but vary among populations within species, between individuals within populations, and within individuals during their lifetime. Some of this variation is genetic, but life-history traits typically exhibit low heritability (Stearns 1992), so other

factors, including phenotypic plasticity, play an important role in the expression of these traits. Understanding patterns of variation in life-history traits is relevant not only to testing evolutionary theory, but also for wildlife management and conservation.

Successful reproduction is fundamental to an organism's fitness. The simplest measure of reproductive output is clutch or litter size, the number of offspring produced on a given occasion. In snakes, clutch or litter size is the most frequently recorded measure of reproductive output and has been the focus of numerous studies of life-history variation within and among species (Seigel and Ford 1987). Here, we focus on inter-population comparisons of a widely distributed species of snake in western North America, Western Gartersnake (*Thamnophis elegans*), which ranges latitudinally from southern Arizona to central British Columbia (Rossman *et al.* 1996). Throughout this range, *T. elegans* occupies a diversity of environments that differ in climate, biophysical characteristics, and other attributes that could influence the expression of life-history traits, including litter size. Other wide-ranging species of gartersnakes show considerable geographic variation in litter size (Gregory and Larsen 1993, 1996; Tuttle and Gregory 2014).

Because litter size in gartersnakes is often strongly correlated with body size of mother (Seigel and Ford 1987), litter size could vary geographically simply because of geographic variation in body size. However,

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in Common Gartersnake (*T. sirtalis*), variation among sites in litter size was not explained solely by maternal size (Gregory and Larsen 1993); both slopes and elevations of the linear relationships between litter size and maternal size varied among populations. Similar variation in litter size-maternal size relationships was observed between two ecotypes of *T. elegans* in California (Bronikowski and Arnold 1999). Unfortunately, Fitch's (1985) early exploration of geographic variation in litter size of *T. elegans* did not incorporate data on maternal body size.

In addition to geographic variation, litter size in snakes also may vary from year to year, depending on weather, either in the current or previous year (Seigel and Fitch 1985; Brown and Shine 2007; Tuttle and Gregory 2014). Variation in weather within and among years affects prey productivity, and therefore availability of resources to snakes for reproduction. As snakes are ectotherms, their activity and ability to acquire resources also could be affected by weather, independently of resource availability, thereby indirectly influencing reproduction.

Here, we revisit a previous study on reproductive characteristics of *T. elegans* at four widely separated sites in British Columbia (BC; Farr and Gregory 1991), to which we have since added substantially more data. Analysis of litter size in our earlier study was confined to comparisons of different ways of estimating litter size within each site. Here, we test the influences of size of mother, location, and year on litter size across all four populations.

Methods

The four study sites were located, respectively, near Creston in the Kootenay region (KOOT, south-eastern BC: 49.12°N, 116.64°W); near Williams Lake in the Chilcotin region (CHIL, central BC: 51.97°N, 122.53°W); at Okanagan Falls in the Okanagan Valley (OKAN, south central BC: 49.34°N, 119.57°W); and near Victoria on Vancouver Island (VANI, southwestern BC: 48.48°N, 123.55°W). These four sites represent distinctly different habitat types. The KOOT site is a complex of extensive marshes bordered by forested slopes, with additional riverside habitat. The CHIL site is a dry, sparsely vegetated grassland with scattered small, isolated ponds. The OKAN site is mainly riverside habitat. Finally, the VANI site is an estuary. All of these sites, except for VANI, were also included in Gregory and Larsen's (1993, 1996) analyses of geographic variation in reproductive characteristics of *T. sirtalis*.

In this study, we recorded litter size through exact counts of offspring borne by gravid females held in captivity until parturition. Our 1991 study consisted of 78 litters collected between 1975 and 1988, albeit not in all years and in different years for each location. For this new analysis, we have added 18 litters from KOOT collected in 1996 for laboratory experiments (Gregory and Skebo 1998; Gregory *et al.* 1999) and 20 from

OKAN collected between 1990 and 2000 (P.T.G. unpubl. data). Conditions under which snakes were maintained in captivity are detailed in Farr and Gregory (1991) and Gregory and Skebo (1998). The additional snakes from OKAN were housed and maintained at University of Victoria as described in Farr and Gregory (1991).

Although most young were born alive, some litters contained dead young and/or undeveloped eggs. From a strictly demographic perspective, only live births matter. However, from an energetic perspective, dead and undeveloped young still represent an investment in reproduction and, together with live young, comprise potential litter size. Furthermore, as it is unclear to what extent the occurrence of dead or undeveloped young is due to stresses experienced by gravid females in captivity (Gregory 2001), excluding these classes of offspring might artificially deflate litter size estimates. Our previous studies suggest that litter size, relative to maternal body size, in a given population is less variable when all components are included (Farr and Gregory 1991; Gregory *et al.* 1992). Finally, counting all litter elements enables comparison with other studies based on estimates of litter size from abdominal palpations in the field or dissections of females in early pregnancy. That is the approach that we have taken here.

In the analyses of variance (ANOVA) and covariance (ANCOVA) that follow, we treat location and year as random factors. Location is a random factor because we did not choose these four study sites for any particular features relevant to life-history variation, but simply because they had populations of *T. elegans*. Similarly, we did not choose years based on weather or any other factors. The years in which we collected data differed for each site, so location and year are not crossed in an orthogonal factorial design; rather, year nested within location is the appropriate model for combined analysis of these two factors. We did all analyses using SAS 9.3 software (SAS Institute Inc. 2011) and a conventional alpha level of 0.05 for rejection of null hypotheses; *F*-tests were based on Type III sums of squares.

We analyzed the data in stages. First, we combined data for all years for each site and did separate one-way ANOVAs among sites of both size of mother (snout-vent length, SVL) and litter size. Second, to separate the effects of maternal SVL and location on litter size, we ran an ANCOVA of litter size among locations (again combining years for each location), with maternal SVL as a covariate. We first ran the analysis with the interaction of SVL \times location included (as a test of homogeneity of slopes), then re-ran it with the interaction removed if that effect was non-significant. Third, for each location, we performed an ANCOVA of litter size among years, again with maternal SVL as a covariate and the same considerations concerning the interaction SVL \times year. Fourth, we combined the data across all locations and years for an overall ANCOVA of litter

size, with maternal SVL as covariate and location and year as factors (year nested within location).

Although litter size is a fundamental life-history trait, it is not the only measure of a female's reproductive output. For example, in snakes, offspring size also often varies with maternal size (Seigel and Ford 1987). Because the variable litter mass incorporates both litter size and offspring size, we repeated the analyses described above with litter mass, rather than litter size, as a dependent variable.

Results

We analyzed data from 118 litters (KOOT: 49 litters over five different years; CHIL: 29 over four; OKAN: 31 over seven; VANI: nine over four). Samples in some years were very small, especially for VANI.

Mean litter size was significantly different among locations (ANOVA, $F_{3,114} = 14.74$, $P < 0.0001$; Figure 1), but the pattern of variation was mirrored by significant differences in mean size of mother among locations ($F_{3,114} = 27.23$, $P < 0.0001$; Figure 2). The test of slope heterogeneity of litter size on maternal SVL among locations was non-significant (interaction between location and SVL, $F_{3,110} = 1.90$, $P = 0.13$), so we dropped the interaction term and proceeded with the ANCOVA, which revealed a highly significant effect of maternal SVL on litter size ($F_{1,113} = 138.66$, $P < 0.0001$), but no difference among locations ($F_{3,113} = 0.41$, $P = 0.75$). Thus, the relationship between litter

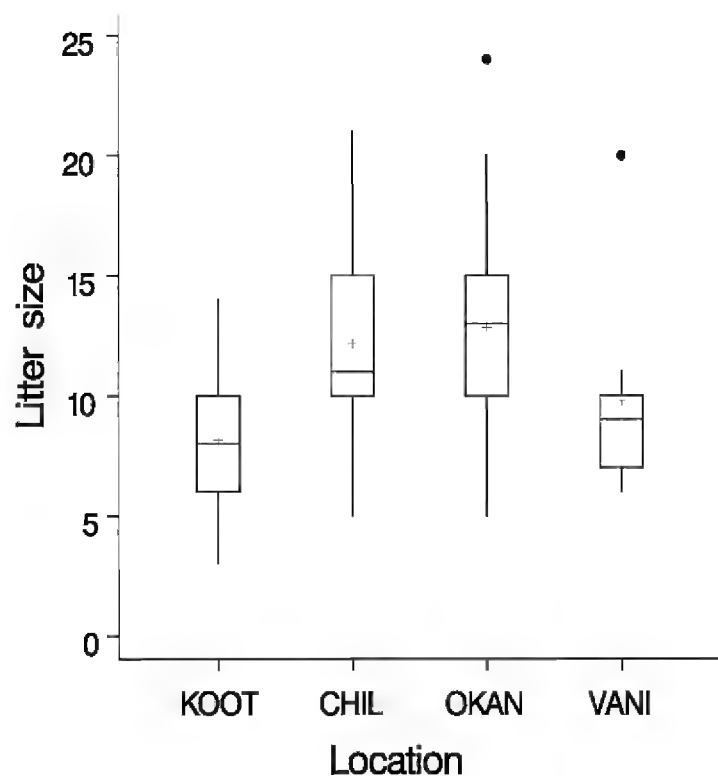


FIGURE 1. Boxplots of litter size of Western Gartersnake (*Thamnophis elegans*) at four sites in British Columbia. Upper and lower ends of boxes represent 75th and 25th percentiles (quartiles), respectively; horizontal line in each box is the median and the mean is indicated by +. Whiskers extend to the most extreme value not exceeding 1.5 times the interquartile distance; individual points represent more extreme observations. KOOT = Kootenay, CHIL = Chilcotin, OKAN = Okanagan, VANI = Vancouver Island. Sample sizes are: KOOT $n = 49$; CHIL $n = 29$; OKAN $n = 31$; VANI $n = 9$.

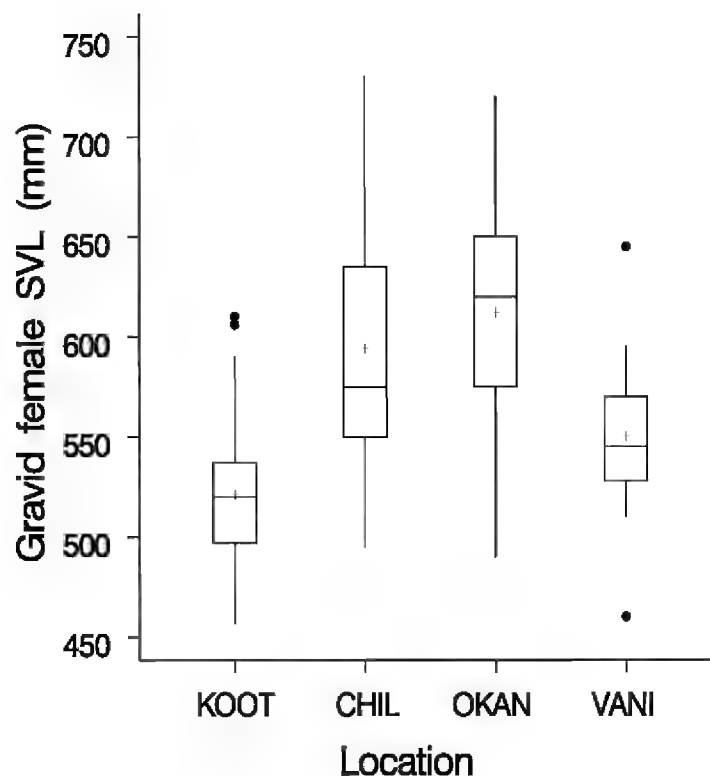


FIGURE 2. Boxplots of body size (snout-vent length, SVL) of gravid female Western Gartersnake (*Thamnophis elegans*) at four sites in British Columbia. See Figure 1 caption for sample sizes and explanation of boxplots. Locations defined as in Figure 1.

size and maternal body size for the four populations was best described by a common linear regression (Litter Size = $0.048 \times \text{Female SVL} - 16.56$, $r^2 = 0.55$, $F_{1,116} = 140.80$, $P < 0.0001$; Figure 3).

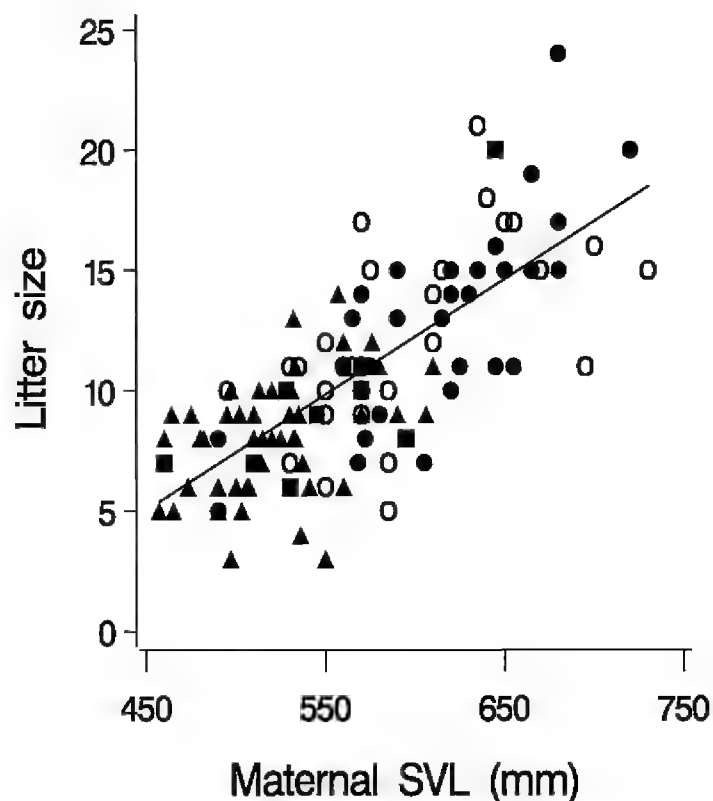


FIGURE 3. Plot of litter size against body size (snout-vent length, SVL) of maternal Western Gartersnake (*Thamnophis elegans*) for four sites in British Columbia. Line represents linear regression of litter size on maternal body size for all locations combined (Litter Size = $0.048 \times \text{Female SVL} - 16.56$). KOOT snakes: triangles ($n = 49$); CHIL snakes: open circles ($n = 29$); OKAN snakes: filled circles ($n = 31$); VANI snakes: squares ($n = 9$). Locations defined as in Figure 1.

When we compared litter size among years for each location, with maternal SVL as a covariate, the interaction between year and maternal SVL was non-significant in each case (Table 1). With no evidence of heterogeneity of slopes, we performed the ANCOVA for each location with the interaction term omitted from the model and found that for each location, there was again a significant positive relationship between litter size and maternal SVL, but no significant variation in litter size among years (Table 2).

The final analysis including all factors again showed that maternal size had a highly significant effect on litter size ($F_{1,97} = 49.51$, $P < 0.0001$), but that neither location ($F_{3,97} = 0.45$, $P = 0.72$) nor year (nested within location; $F_{16,97} = 0.76$, $P = 0.73$) significantly influenced litter size. Overall r^2 for this analysis was 0.60, leaving 0.40 of the total variation in litter size as residual or unattributed.

Litter mass was highly correlated with litter size ($r = 0.87$, $n = 107$, $P < 0.0001$) and the analysis of litter mass essentially duplicated that of litter size, so we omit those additional results here.

TABLE 1. Tests of heterogeneity of slopes of litter size against maternal snout-vent length (SVL) among years (SVL \times year interaction) for Western Gartersnake (*Thamnophis elegans*) at each study site. Main effects (SVL, year) also were included in the model, but results are not shown (see Table 2 for these effects in reduced ANCOVA model). KOOT = Kootenay, CHIL = Chilcotin, OKAN = Okanagan, VANI = Vancouver Island.

Location	F_{df}	P
KOOT	1.14 _{4,39}	0.35
CHIL	1.21 _{2,22}	0.32
OKAN	1.65 _{5,18}	0.20
VANI	3.90 _{1,3}	0.14

TABLE 2. Analyses of covariance (ANCOVA) of litter size among years, with maternal snout-vent length (SVL) as covariate, for Western Gartersnake (*Thamnophis elegans*) at each study site. Slopes of regression of litter size on maternal SVL were homogeneous among years in each case (see Table 1). Locations defined as in Table 1.

Location	Test	F_{df}	P
KOOT	SVL	7.46 _{1,43}	0.0091
	Year	0.61 _{4,43}	0.6549
CHIL	SVL	11.78 _{1,24}	0.0022
	Year	0.11 _{3,24}	0.9546
OKAN	SVL	23.41 _{1,23}	< 0.0001
	Year	0.70 _{6,23}	0.6536
VANI	SVL	5.90 _{1,4}	0.0720
	Year	1.33 _{3,4}	0.3811

Discussion

It is worth considering at the outset the degree to which our conclusions were influenced by the methods we used. Holding gravid females in captivity may have a number of effects on litter characteristics because the

gravid snake is not usually free to feed or thermoregulate in the same manner as a wild snake (Farr and Gregory 1991). The overall ANCOVA model that we used has practical limitations (Ballinger 1983) and our data set represents an imperfect nested design (e.g., the data are non-orthogonal, years within location were not chosen strictly at random). Nevertheless, our analysis contributes to a broader understanding of geographic and temporal variation in litter size of *T. elegans* and suggests directions for future studies.

Our study has three major findings: litter size of *T. elegans* varies significantly among populations, significant differences in maternal body size among populations account for much of the observed variation in litter size, and little geographic or temporal variation in litter size remains after effects of maternal body size are taken into account. Thus, most of the residual variation in litter size (after maternal size effects have been removed) is due to further differences among individual mothers and/or other unmeasured factors.

Two important issues emerge from this analysis. First, because litter size varies with maternal body size, which varies significantly among populations, we need to explain geographic variation in body size. Second, we need to determine the extent to which variation in litter size among individual females is determined by genetic or environmental factors (e.g., differences in foraging success).

Significant body-size variation among populations has been observed for numerous snake species (e.g., Semlitsch and Moran 1984; Schwaner 1985; Plummer 1987; King 1989; Gregory and Larsen 1993, 1996; Madsen and Shine 1993; Tuttle and Gregory 2012), but explanations vary. For example, body size often increases with size and/or availability of prey (Schwaner 1985; Shine 1987; Madsen and Shine 1993; Boback 2003; Filippakopoulou *et al.* 2014). Smaller size might also be partly attributable to higher mortality from various causes, including predation (King 1989; Filippakopoulou *et al.* 2014). Climate may also play a role. The temperature-size rule predicts that ectotherms should grow more slowly, but reach larger sizes, in colder environments (Angilletta and Dunham 2003). However, departure from the temperature-size rule is common (Tuttle and Gregory 2012) and most species of snakes are actually smaller at higher latitudes and elevations (Ashton and Feldman 2003).

At present, we can offer no explanation for the pattern of body size variation that we observed in *T. elegans* in British Columbia. However, the two sites with relatively large *T. elegans* in our study (CHIL and OKAN) also had larger *T. sirtalis* than most other sites in Gregory and Larsen's (1993) comparative study of that species, suggesting that similar environmental factors may explain at least some variation in body size within these two closely related species.

Thamnophis elegans is a wide-ranging species, but there has been little documentation of geographic variation in its reproductive characteristics. Based on data

from several subspecies combined, Fitch (1985) showed that litter size generally declined from the southern part of the range to the north. Although our data for KOOT and VANI are consistent with this trend, litter sizes of *T. elegans* from CHIL and OKAN are much larger than those from farther south. In fact, the mean litter size (12.8) and maximum litter size (24) that we recorded for OKAN snakes are larger than any reported by Fitch (1985). However, Bronikowski and Arnold (1999) reported similar maximum litter size for large *T. elegans* in northern California. Unfortunately, Fitch's (1985) analysis did not include body sizes of snakes, limiting its comparative value here.

The consistent relationship between litter and maternal body size that we observed for *T. elegans* in British Columbia contrasts observations for populations in northern California. There, lakeshore and meadow ecotypes of *T. elegans* occur in contrasting environments and exhibit differences in numerous life-history traits, including the relationship between litter size and maternal size (Bronikowski and Arnold 1999). The overall relationship that we observed is very similar to that seen for the meadow ecotype; in contrast, lakeshore snakes have a steeper relationship (Bronikowski and Arnold 1999). It would be informative to determine whether British Columbia populations also match the California meadow ecotype in other life-history traits.

Other species also show geographic variation in the litter size-maternal size relationship. For example, in *T. sirtalis*, the relationship between litter size and maternal SVL varies strongly among populations, in both slope and intercept (Larsen and Gregory 1993), especially between eastern and western Canada (Gregory and Larsen 1996). Populations of *T. sirtalis* range from those comprised of small females that produce large numbers of young to those consisting of large females that produce small litters. Correlated with this is variation in neonate size, large litter size usually being accompanied by small offspring (Larsen and Gregory 1993). However, offspring size of *T. elegans* varies relatively little among our study sites (Farr and Gregory 1991). Geographic differences in the relationship between litter size and maternal size also have been observed in Red-bellied Snake (*Storeria occipitomaculata*; Semlitsch and Moran 1984; Brodie and Ducey 1989). In all of these studies, geographic variation in body size accounts for only a small fraction of the variation in litter size.

A perhaps surprising result of our study is the lack of variation among years in litter size, but our samples were small. That said, Brodie and Ducey (1989) also found no significant variation between years in maternal size-adjusted litter size of *S. occipitomaculata*. In Rough Greensnake (*Opheodrys aestivus*) clutch size did not vary among years at one site (Plummer 1983) but did at a second site (Plummer 1997). Seigel and Fitch (1985) determined that, even after correcting for differences in maternal body size, clutch size varied signifi-

cantly among years in four populations (different species) of snakes, and that this variation was related to rainfall (larger litter sizes in wetter years). This finding prompted Seigel and Fitch (1985) to caution researchers about the limitations of data from short-term (especially from just one year) studies to characterize reproductive habits, an admonition with which we concur. The temporal variations in clutch size reported by Seigel and Fitch (1985) far exceed those that we observed, and it is possible that the environment in their study area (Kansas) is more variable than any of ours. In most cases, their samples extended over a greater number of years than did ours, increasing the likelihood of observing extreme values. Litter size of Plains Gartersnake (*Thamnophis radix*) in Alberta also varies among years in relation to the previous year's rainfall and temperature (Tuttle and Gregory 2014). In addition to the temperate-zone snakes cited above, weather-related annual variation in clutch or litter sizes have been reported in tropical snakes (Brown and Shine 2007) and in other reptilian taxa (e.g., Bleu *et al.* 2013; Hedrick *et al.* 2018).

Weather per se presumably has an indirect effect on clutch size through resource acquisition, possibly by limiting activity and foraging opportunities (e.g., in cool conditions; Tuttle and Gregory 2014) or by influencing prey abundance and availability. For example, Seigel and Fitch (1985) attributed higher clutch size of Ring-necked Snake (*Diadophis punctatus*) in wet years to increased prey availability. Other studies have explicitly demonstrated the link between year-to-year variation in litter size and prey availability, whether driven by weather or other factors (Andr n and Nilson 1983; Brown and Shine 2007; King *et al.* 2008). However, in Brown Water Python (*Liasis fuscus*) changes in prey availability influenced clutch size only slightly, instead affecting the post-oviposition body condition of females (Madsen and Shine 1999).

The search for general patterns among diverse groups of organisms is a central aim of life-history research. But comparative studies also are needed at the intraspecific level, because potentially confounding phylogenetic factors are reduced in such studies and because they should allow us to distinguish proximal from evolutionary causes of variation (Brown 1983). The issue of genetic versus non-genetic sources of variation will not be a simple one to resolve (Ballinger 1983; Stearns 1992). But we believe that it is essential to understand the degree to which important traits vary naturally in the field, both spatially and temporally, to provide the background against which to interpret eventual experimental results.

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Note

Erythrism in Spring Peeper (*Pseudacris crucifer*) in Maritime Canada

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Abstract

We document three cases of erythrism in Spring Peeper (*Pseudacris crucifer*) in New Brunswick and Nova Scotia. Although the source of erythrism in Maritime *P. crucifer* remains uncertain, the occurrences reported here demonstrate this colour morph to be a widespread, although apparently rare, form in the Canadian Maritimes region.

Key words: Spring Peeper; *Pseudacris crucifer*; amphibian; colour variant; New Brunswick; Nova Scotia

Kolenda *et al.* (2017) noted that the documentation of colour anomalies may contribute to our understanding of the ecological history and phenotypic plasticity of species and recorded a variety of colour aberrations in amphibians. In amphibians, albinism (lack of pigment) and leucism (partial loss of pigment) seem to predominate; axanthism (loss of yellow pigment) may be less common (Dyrkacz 1981; Betchtel 1995; Jablonski *et al.* 2014). Erythrism (abnormal redness) appears to be rare in amphibians, although Moore and Ouellet (2014) reported prevalences of erythrism in Red-backed Salamander (*Plethodon cinereus*) as high as 50%. Chromatophores fortified with pteridines, carotenoids, or flavins generally underlie red-yellow colouration in lower vertebrates (Hubbard *et al.* 2010), including amphibians (Hoffman and Blouin 2000). Recent evidence shows that pheomelanin may also be responsible (Wolnicka-Glubisz *et al.* 2012).

Cases of erythrism in amphibians in Maritime Canada have previously been restricted to Red-backed Salamander. Bleakney and Cook (1957) and Gilhen (1968) have reported erythristic individuals from Nova Scotia, while Cook and Bleakney (1961), Ekstrom (1973), and Jongsma (2012) have all reported this colour form of the species in New Brunswick. There are, apparently, no reports of erythrism in amphibians from Prince Edward Island (Cook 1967; Moore and Ouellet 2014).

Although skin colour in Spring Peeper (*Pseudacris crucifer*) may vary, adults and juveniles are normally light tan through dark brown to grey, usually with a distinctive, dark, x-shaped mark on the back, dark banding or spotting on the legs, and a dark stripe on the side of the head (Dodd 2013). Cook (1967) and Gilhen (1984) reported that Maritime Spring Peepers likewise range in colour through shades of brown or grey, but the x-shaped pattern on the back is usually distorted or fragmented and connected to additional markings (Figure 1).

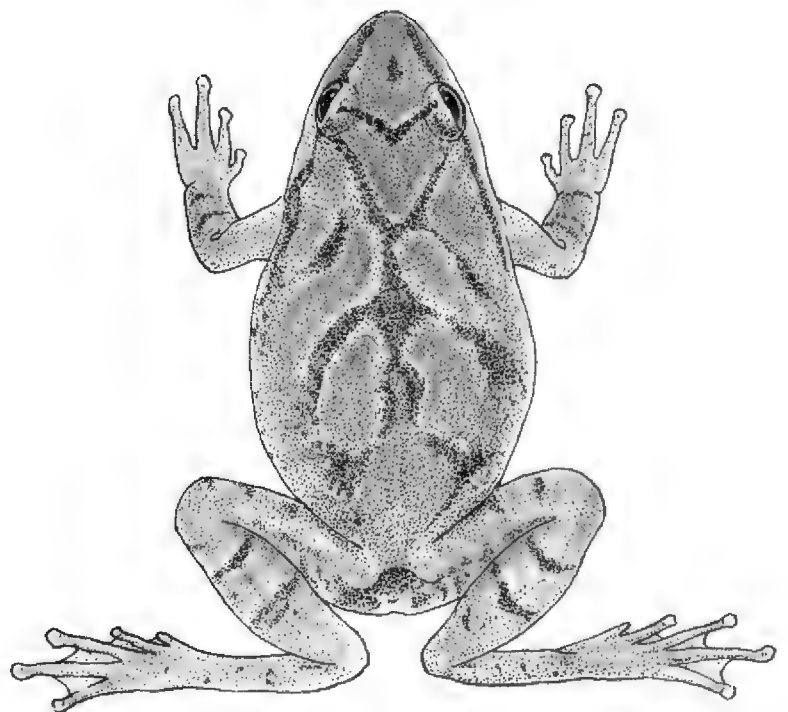


FIGURE 1. Male specimen of Spring Peeper (*Pseudacris crucifer*) from Prince Edward Island showing normal colour morph for Maritime Canada. Note the fragmented x-marking on the back, characteristic of the species in the region. Original line drawing of Canadian Museum of Nature specimen 3956-4 scanned from Cook (1967) and tinted with chalk pastels by A. Karstad.

Here we document cases of erythrism in Spring Peepers from Maritime Canada reported to us at the Nova Scotia and New Brunswick Museums by members of the public.

On 30 September 2008, observer 1 discovered a uniformly orange Spring Peeper inside an empty paint tin at L'Ardoise, Richmond County, Cape Breton, Nova Scotia (45.6151°N, 60.7663°W; Figure 2A). On 16 September 2014, observer 2 reported a (juvenile) uniformly orange Spring Peeper on a screen door 2 km east of the Petitcodiac Bridge, Riverview, New Brunswick (46.0687°N, 64.7801°W; Figure 2B). On 18 September

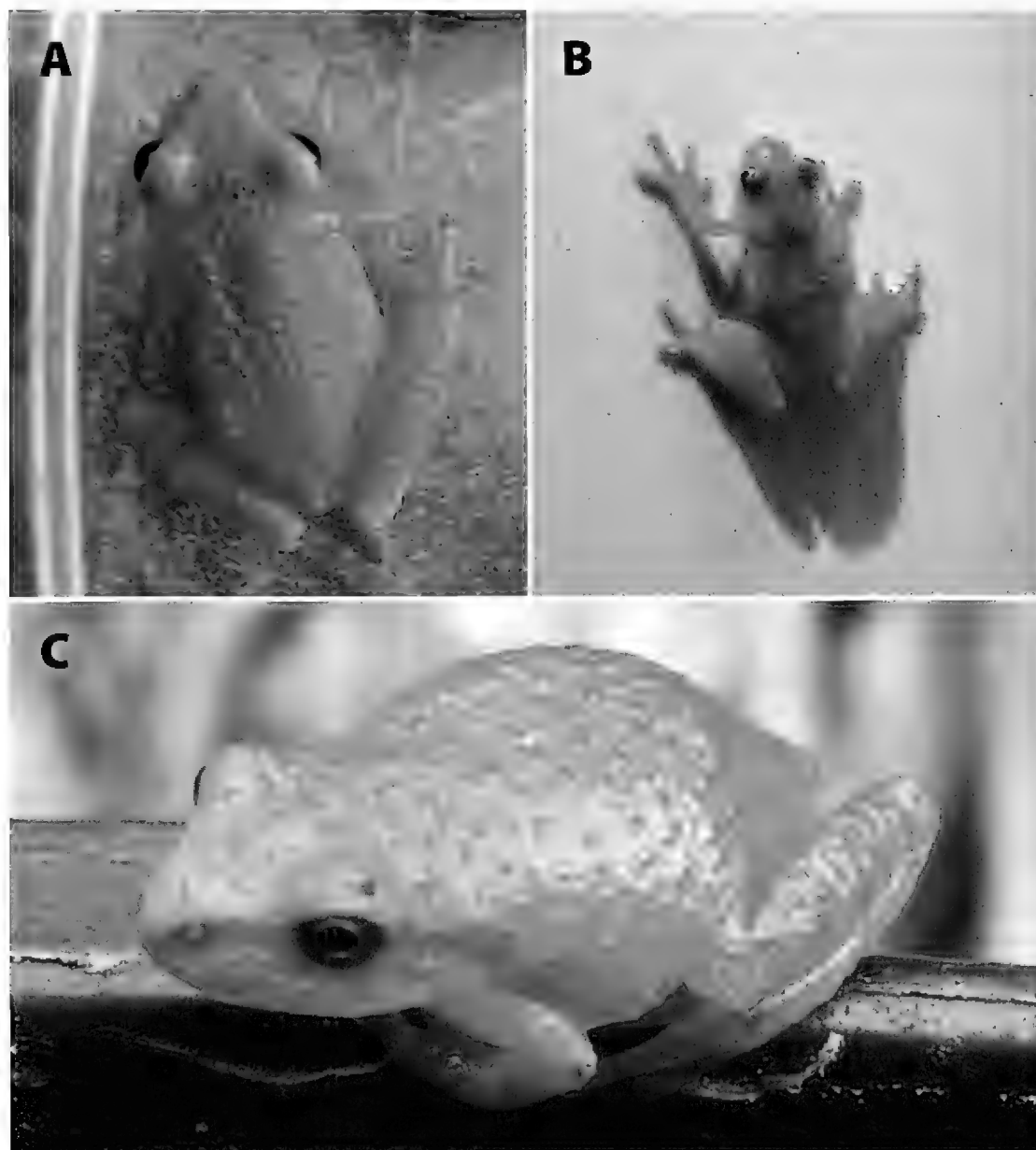


FIGURE 2. Three erythristic specimens of Spring Peeper (*Pseudacris crucifer*) from Maritime Canada: (A) L'Ardoise, Richmond County, Cape Breton, Nova Scotia; (B) Riverview, Westmorland County, New Brunswick; (C) Duncan's Cove, Halifax County, Nova Scotia. Photos: Nova Scotia Museum files.

2016, observer 3 photographed a uniformly orange Spring Peeper at Duncan's Cove, Halifax County, Nova Scotia (44.4990°N, 63.5258°W; Figure 2C). Each of these erythristic Spring Peepers lacked the x-shaped mark on the dorsum, and banding on the legs and face was reduced.

Kolenda *et al.* (2017) hypothesized that cases of erythrism in Common Eurasian Spadefoot Toad (*Pelobates fuscus*) in Poland are the result of high iron concentrations in water and soil, presumably intensifying the colour of erythrophores. Umbers *et al.* (2016) found that dietary carotenoids influence the saturation and hue of yellow pigments in Australian Southern Corroboree Frog (*Pseudophryne corroboree*). Thurow (1961) attributed genetic, rather than environmental factors, to the presence of erythrism in Red-backed Salamander. Others have suggested that the erythristic form of this species may be a Batesian mimic of the terrestrial eft stage of the predator-toxic Red-spotted Newt (*Notophthalmus viridescens*; Cassell and Jones 2005 and references cited therein).

There appear to be no previous reports of erythrism in *Pseudacris crucifer*, although Telford (1952) briefly mentioned the collection of two "brick red" Little Grass Frogs (*Pseudacris ocularis*) in Florida. Although the source of erythrism in Maritime Spring Peepers remains uncertain, the three occurrences reported here demonstrate this colour morph to be a widespread, although apparently rare, form in the Canadian Maritimes region. We encourage further reporting of erythrism in Spring Peepers and other Canadian amphibians.

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Ready for bed: pre-hibernation movements and habitat use by Fowler's Toads (*Anaxyrus fowleri*)

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Abstract

We used radio-tracking to investigate movement patterns and habitat use of Fowler's Toads (*Anaxyrus fowleri*) during late summer and early fall in a relatively undisturbed lakeshore dune and beach habitat at Long Point, Ontario. Small radio transmitters were fitted to 11 adult toads with an external harness made from fine surgical plastic tubing wrapped around the body behind the front limbs. We located radio-tagged toads morning and evening, for a maximum of 9 days, recording their locations using Global Positioning System units. Initially, the toads were located on the upper beach or in the fore-dunes during the day, either dug in under the sand or hiding beneath debris; in the evening, they were generally active on the lower beach close to the water line. After a storm and the onset of cooler autumn weather, the toads tended to move further from the water line. They also curtailed their nightly activity and retreated deeper into the sand. As this sort of behaviour was not observed during the summer, we interpret it as pre-hibernation movement to more stable sites away from the beach where the animals can burrow deeply into the sand to lie dormant during the winter.

Key words: Fowler's Toad; *Anaxyrus fowleri*; radio-tracking; amphibian; habitat use; behaviour; movement; spatial ecology; hibernation; Long Point; Ontario

Introduction

Compared with their spring movements to aquatic breeding sites, the autumnal movements of temperate zone, pond-breeding amphibians to overwintering sites are not well understood (Miwa 2017). However, there is evidence that anurans may alter their habitat preferences late in their active season and begin to seek particular sites for hibernation that they would otherwise tend not to use (Koskela and Pasanen 1974; Bull 2006; Lee and Park 2009; Yu and Guo 2010; Ludwig *et al.* 2013). For example, Canadian Toads (*Anaxyrus hemiophrys*) in Minnesota are known to hibernate deep inside earthen mounds on the prairie (Tester and Breckenridge 1964), whereas Western Toads (*A. boreas*) in Alberta may overwinter in peat hummocks, squirrel middens, cavities under spruce trees, or other such sheltered sites (Browne and Paszkowski 2010a). In both cases, particular habitat features allow the animals to retreat deeply into the ground to escape inhospitable surface conditions. The animals' use of these habitats suggests that they alter their behaviour to seek out such sites as winter approaches (Browne and Paszkowski 2010b).

At its northern range limit, Fowler's Toad (*Anaxyrus fowleri*) is a shoreline beach and sand dune specialist (Breden 1988; Green 2005). At night, during summer, individuals forage along wet, sandy shores. By day, they either seek refuge under debris or bask in the warm sand of the fore-dunes that line the beach (Marchand *et al.* 2017). However, such shore-facing sites are highly

vulnerable to disturbance during winter storms and are, therefore, unlikely to provide sufficient protection for overwintering animals. To survive the winter, the toads must be able to dig deeply enough into the ground to escape penetrating ground frost at sites that are sheltered from severe weather and protected from flooding.

Thus, they should have quite different microhabitat preferences for overwintering sites compared with summer refuge sites and should begin their pre-hibernation movements to such sites coincident with particular environmental conditions as summer turns into fall. The opportunity to study such movements arose during the course of a radio-tracking study of Fowler's Toads toward the end of their active season at Long Point, Ontario, when a severe storm brought a significant change in the weather.

Methods

Study site

The Big Creek National Wildlife Area (Figure 1) is at the western base of Long Point, Ontario, on the north shore of Lake Erie (42°34'N, 80°28'W). Inland from the lake lies a sandy beach largely devoid of vegetation, then dunes and marsh. The fore-dunes facing the beach are vegetated largely with American Beachgrass (*Amphipha breviligulata* Fernald) and Riverbank Grape (*Vitis riparia* Michaux), whereas the dune tops and back-dunes feature a variety of forbs, willow shrubs (*Salix* spp.), and Eastern Cottonwoods (*Populus del-*

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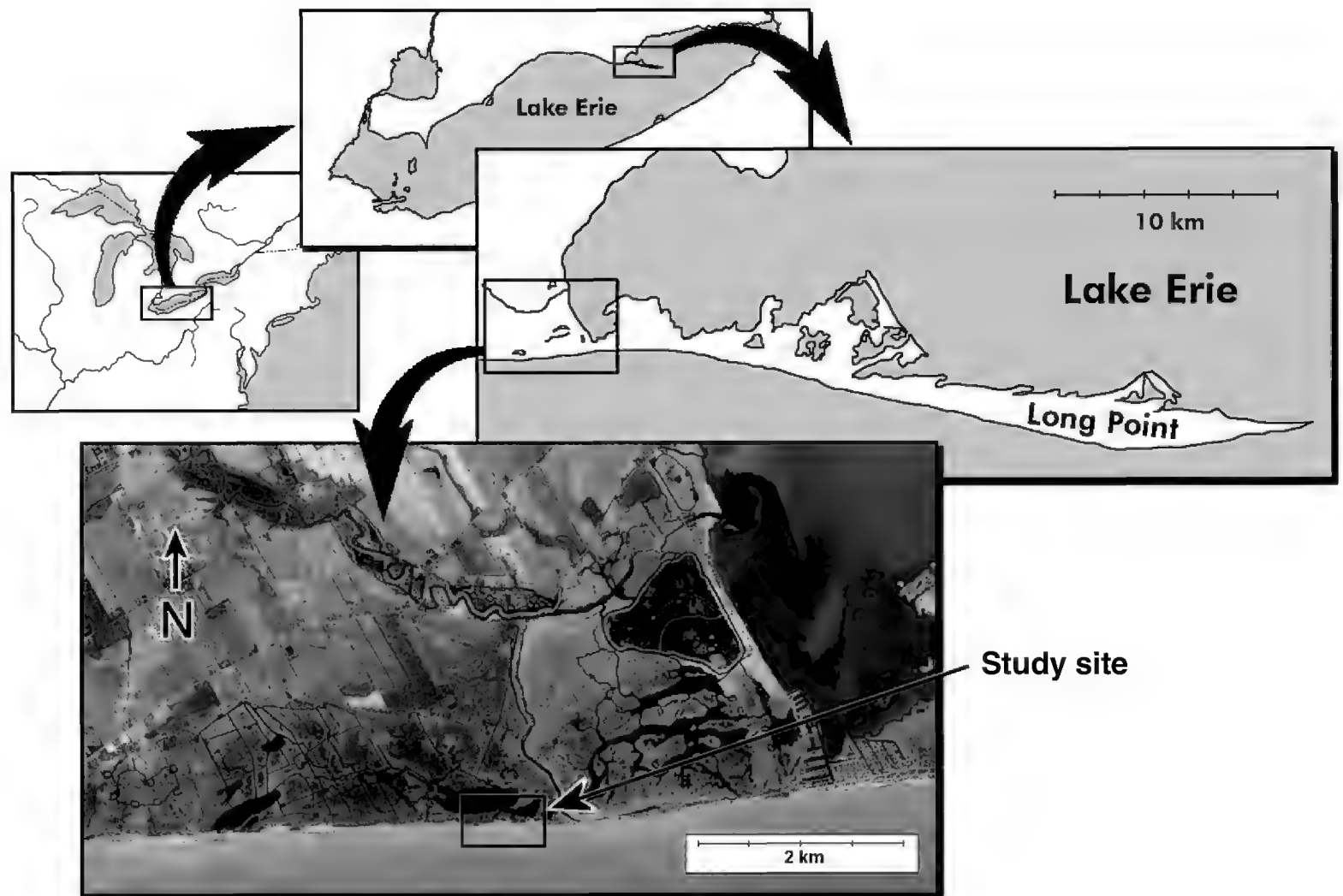


FIGURE 1. Location of the study site at Big Creek National Wildlife Area, Long Point, Ontario (42°34'N, 80°28'W). Aerial photo courtesy of Ontario Ministry of Natural Resources and Forestry.

toides W. Bartram ex Marshall). Historically, marshland located just north of the dunes and dominated by cat-tails (*Typha* spp.) and Common Reeds (*Phragmites australis* (Cavanilles) Trinius ex Steudel) served as spring breeding habitat for the toads (Green 1989, 2005). We obtained temperature and wind speed data for the study period (30 August to 8 September 2008) from the records of the LONG POINT (AUT) weather station, located about 33 km to the east, near the tip of Long Point (Environment Canada 2013).

Radio-tracking

We used radio-tracking (Marchand *et al.* 2017) to locate animals in the morning and evening from 30 August to 8 September 2008. We tagged adult toads with an external 0.51-g BD-2 radio-transmitter (Holo-hil Systems Ltd., Carp, Ontario, Canada) attached to a harness made of plastic surgical tubing with monofilament fishing line threaded through it to enable us to tie it around the toad's body (Figure 2). We attached the harness behind the toad's front limbs, rather than around the waist (Bartelt and Peterson 2000), so that it would not interfere with the animal's ability to dig into the ground. Toads were captured and tagged in the evening when they were active and tracked beginning the following morning.

We measured the snout-to-vent length (SVL) of each individual using dial calipers, noted its sex, photo-

graphed it for later identification, and assigned it an identity number for reference. As toads have specific patterns of blotches and spots on their backs (Schoen *et al.* 2015), we could readily identify each individual by comparing it to its photograph. We released all toads at the point of capture immediately after they had been tagged.

We located the radio-tagged toads every morning, when they were dormant, and evening, when they were usually active on the beach, using an HR2600 Osprey receiver (H.A.B.I.T. Research, Victoria, British Columbia, Canada) and a three-element Yagi antenna. In the morning, we checked to determine that transmitters were still properly attached to the tagged toads. Usually, we could do this visually without disturbing the animal, as the resting toads were most often at or close to the surface of the sand, with the transmitter's antenna clearly visible. If neither the toad nor its transmitter was visible at the surface, we carefully pushed aside the sand to locate it and register how deeply the toad had buried itself, with minimal disturbance to the animal. In the evening, we captured all tagged toads that were active to check the condition of the harness. We removed the harness if we saw any signs of abrasion and tagged a different toad if we could find one. We tagged an initial three toads on the first evening of the study and three more on the second evening. Thereafter, we tracked up to seven toads at a time.

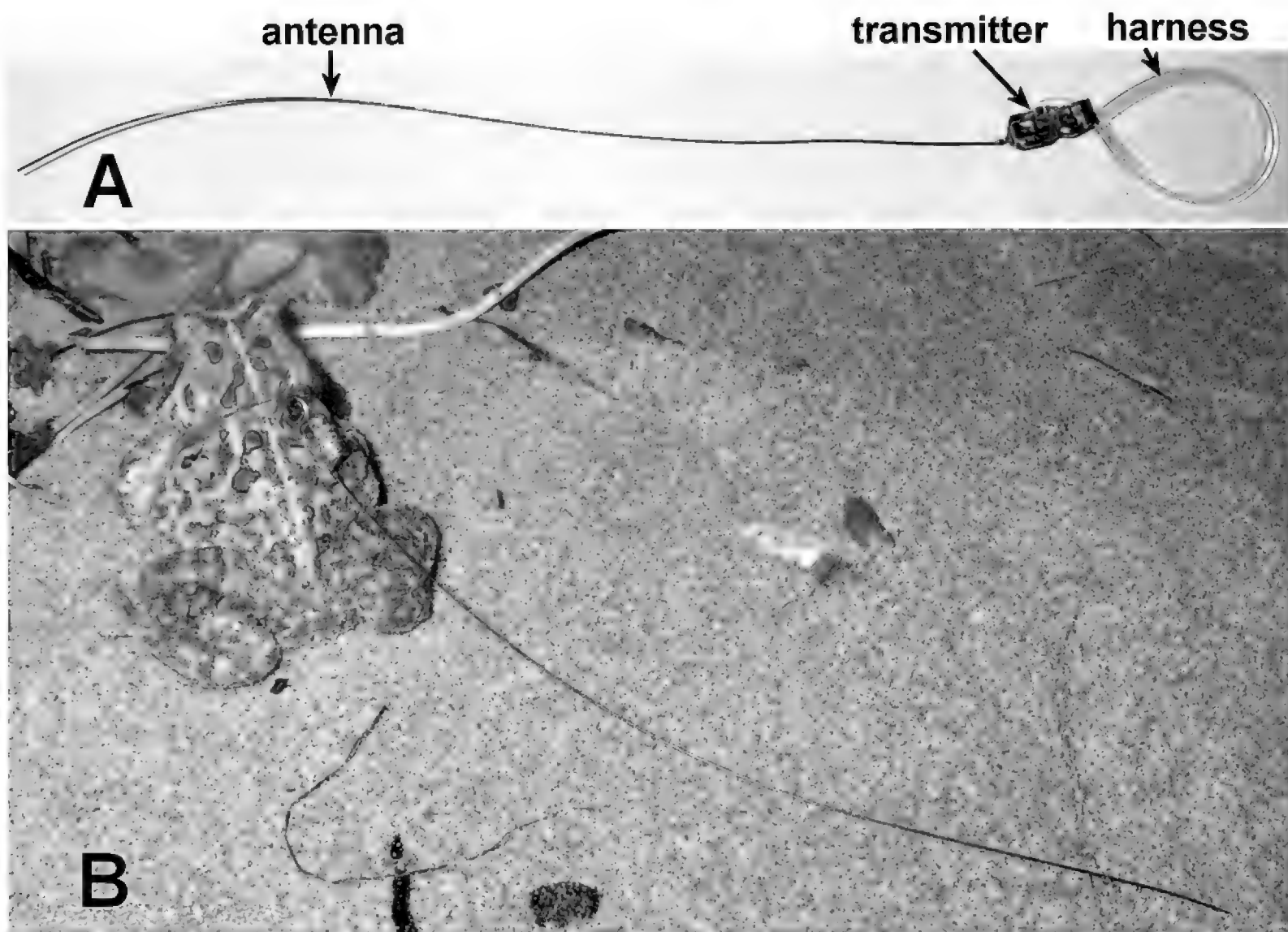


FIGURE 2. Radio-transmitter, showing harness (A) and attachment to a Fowler's Toad (*Anaxyrus fowleri*; B). Photos: D.M. Green.

Mapping

We mapped the locations of radio-tagged toads as universal transverse mercator (UTM) coordinates (NAD 83 datum) with accuracy better than 3 m using a Magellan Mobile Mapper 6 global positioning system unit and Mobile Mapper software (MiTAC Digital Corp., San Dimas, California, USA). We saved all coordinates as .shp files to download into ArcPad 7.1.1.12 software (ESRI Inc., Redlands, California, USA). We used a geo-referenced aerial photo of the region dated 2006 as the base map.

Analysis

We calculated distances travelled by the toads between mapped locations, including total straight-line distance, distance parallel to the water line, and distance perpendicular to the water line. The beach runs in an east–west direction, so distances travelled by the toads east or west parallel to the water line were calculated as the difference between each capture's easting; distances travelled north or south, perpendicular to the water line, were calculated as the difference between each capture's northing. We calculated the toads' daily average movements by correcting for the number of days over which the distances were travelled. We also computed the average distances the toads moved over 24 h (night-to-night and day-to-day) to provide esti-

mates of nighttime activity and distances between daytime refuges. To test whether the toads tended to change the location of their daytime refuge sites to areas further away from the lake in response to the change in the weather following the storm, we used mixed effects linear regression to compare distances of refuge sites away from the Lake Erie water line, with timing (pre-storm versus post-storm) as a fixed effect and the individual toads as a random effect.

Results

Weather conditions during the study

During the first five days of the study, the weather remained clear and dry with daytime high air temperatures around 24°C, nighttime lows around 19°C, light winds under 20 km/h, and very little surf on the lake (Figure 3). On the evening of 4 September 2008, a strong storm with south winds up to 57 km/h brought waves high up the beach that altered or obliterated many of the minor features of the beach, including beach pools. Toads were inactive during the storm. The weather became variable after that, with alternating periods of sun and clouds, some showers, occasional thunderstorms, and winds up to 37 km/h. The temperature rose to 25°C as the storm hit, then fell to 15°C before oscillating between 17°C and 20°C for several days afterward.

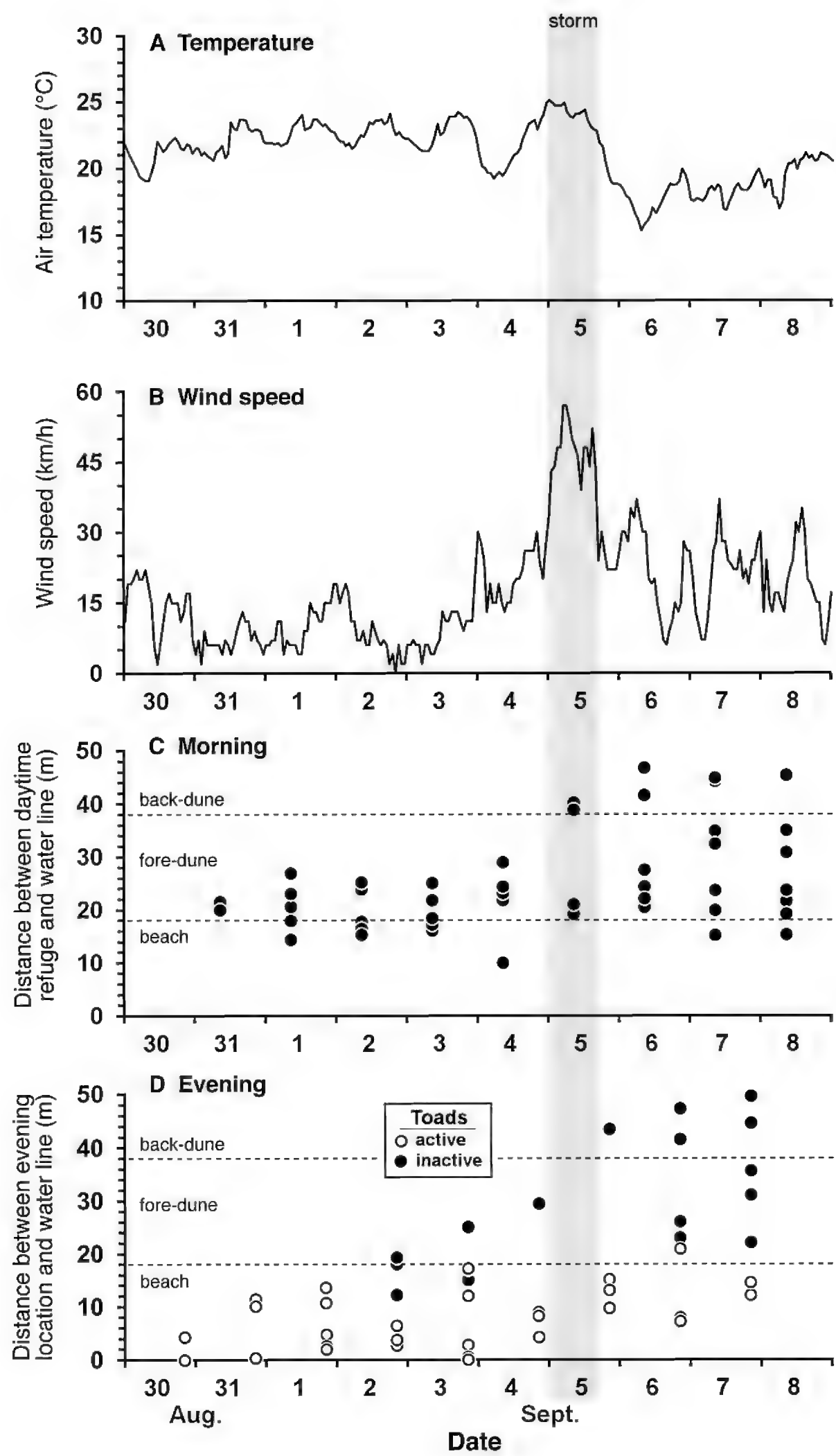


FIGURE 3. Weather conditions and locations of Fowler’s Toads (*Anaxyrus fowleri*) relative to the Lake Erie water line at Big Creek National Wildlife Area, Long Point, during the study period (30 August to 8 September). The timing of a storm accompanied by high waves on the beach is indicated by the grey bar. A. Air temperature. B. Wind speed. C. Distance of daytime refuges of toads from the water line. D. Distance of evening locations of toads from the water line.

Toad movements and habitat use

We located and radio-tagged a total of 11 toads (Table 1), consisting of four females (mean \pm SE SVL = 64.8 ± 3.0 mm) and seven males (SVL = 58.2 ± 0.4 mm). We were able to track two of these toads continuously for all nine days but the average number of tracking days was 4.7 per toad. Four toads managed to shed their transmitters, one after only a day, but we found two of these animals again, two and four days later. Four toads, with their transmitters, disappeared and could not be relocated. Three toads that had worn the harnesses for five days or more showed signs of abrasion behind the parotoid glands. Six transmitters were recovered at the end of the study.

For the most part, the toads moved within a limited area mainly travelling to and along the lower part of the beach on the damp sand at night and retreating to hiding places in the dry sand at the top of the beach and fore-dune during the day. Total distances travelled by toads during the study period ranged from 34 m to well over 600 m (Table 1). Daily average movements ranged from 14.2 m/day to about 125 m/day. Movements parallel to the water line ranged from about 11 m to over 440 m. Long-distance displacements of over 100 m by three toads occurred while they were active at night on the lower and upper beach. Toad 5 used the same hiding place consistently during the day for several days before embarking on an extensive trek 273 m westward. Toad 9 also exhibited long-distance movements parallel to the water line, traversing 441 m in two days, and then used the same refuge site for the next three days. Two toads were relatively sedentary: toad six moved only 26.7 m parallel to the shore over eight days, whereas toad eight moved 17.3 m over six days. Toads were found largely in areas characterized by relatively un-vegetated dunes and the absence of invasive Common Reeds.

Movements perpendicular to the water line were constrained by the width of the beach, but tended to

increase after the storm as toads ventured further away from water to find daytime refugia (Figure 3). Before the storm, toads were located by day in refuge sites on the upper beach and fore-dune, on average 20.0 ± 0.9 m ($n = 26$) from the water line. Some of the animals used particular refuge sites, such as a hollow under a driftwood log, over many days or buried themselves in the sand to a depth of 3–5 cm, generally no deeper than the surface layer of dry sand. Most often, however, animals were found partly buried in dry sand with head and back exposed.

Following the storm, we noted a tendency for the animals to dig deeper into sand at refuge sites farther from the water line. Toad 3, for example, moved to the back-dune immediately after the storm was over, 11.3 m further from the water line, and dug down 60 cm into the sand. Toads 1, 6, and 8 also descended over 30 cm into the sand. Toad 9 moved 10.5 m further from the water line and toads 10 and 11 found refuges sites farther inland than any of the refuges used by any toads before the storm. The animals' daytime refuge sites were found an average of 29.2 ± 2.1 m ($n = 25$) from the water line after the storm, a significantly greater distance than before the storm (mixed effects linear regression: $F_{1,42.8} = 22.2, P < 0.001$).

Discussion

Movement behaviour

Our results corroborate observations that Fowler's Toads inhabiting lakeshore habitats move on a daily basis between lakeside foraging sites at night and sand dune refuge sites during the day (Breden 1988; Marchand *et al.* 2017). Generally, the toads move very little, but there are occasional movements over larger distances, consistent with a generalized, fat-tailed Lévy-type distribution of movement distances (Marchand *et al.* 2017). Because the toads are evidently capable of travelling over 200 m in a day, dispersal movements

TABLE 1. Movements of Fowler's Toads (*Anaxyrus fowleri*) at the Big Creek National Wildlife Area, Ontario, over 10 days in August and September 2008.

Toad no.	SVL, mm	Sex	No. of days tracked	Distance moved, m		Extent of movement, m	
				Total	Mean/day	East–west*	North–south*
1	57.1	♂	9.0	229	25.4	57.1	22.9
2	62.2	♀	9.0	496	55.1	102.1	24.4
3	72.6	♀	9.0	164	18.2	40.2	45.2
4	66.1	♀	2.0	34	17.0	10.9	20.3
5	58.5	♂	4.0	377	94.3	298.1	19.7
6	58.4	♂	8.0	130	16.2	26.7	39.1
7	59.4	♂	2.0	78	39.0	71.7	13.3
8	59.7	♂	6.0	85	14.2	17.3	21.9
9	58.3	♀	5.0	623	124.6	442.2	17.0
10	57.8	♂	4.0	174	43.4	76.2	32.4
11	56.8	♂	4.5	78	17.4	26.7	49.6

Note: SVL = snout-to-vent length.
*East–west movement was parallel to the Lake Erie water line and north–south was perpendicular to the water line.

of many kilometres along the lakeshore in a season are feasible (Smith and Green 2006).

Pre-hibernation behaviour

After the storm, the toads appeared to be readying themselves for winter dormancy. Several animals appeared to respond to changes in weather conditions by shifting their movement and refuge-seeking behaviour to sites away from the more dynamic fore-dunes facing the beach to the protected back-dunes on the leeward side. We also observed that once individuals shifted their refuge sites further from the beach, they were less likely to resume their nightly nocturnal activity, foraging along the lakeshore beach. Instead they buried themselves deeper into the sand. None of these observed behaviours was apparent during summer (Boenke 2011).

It is possible that the high waves on the beach during the storm may have, in part, triggered this response. Natterjack Toads (*Epidalia calamita*) in Britain have been observed to shift refuge sites in response to tidal inundation (Denton and Beebee 1993). More probably, however, the combination of environment conditions, such as colder temperatures, increased rainfall, and decreased day length that appears to evoke pre-hibernation movements in other anurans (Koskela and Pasanen 1974; Miwa 2017) also contributed to the behavioural changes seen in these toads. Fowler's Toads at Long Point are not active in the spring at temperatures below 14°C (Green 1989, 2005); thus, the nighttime low temperatures following the storm approached the lower limits of the toad's normal activity range.

Based on our findings, it seems apparent that the active season for Fowler's Toads may typically come to an end in early to mid-September at the latitude of Long Point. As these toads typically emerge from hibernation in early to mid-May (Green *et al.* 2016), their active season lasts only about four months, compared with eight months of winter dormancy. Shifting their refuge habitat preferences to sites more likely to enable overwinter survival would appear to be a favoured adaptive response.

Acknowledgements

We dedicate this paper to Francis R. Cook whose devotion to the study of natural history, in general, and amphibians, in particular, inspired the growth of herpetology in Canada. We thank the Ontario Ministry of Natural Resources and Forestry for aerial map imagery and the Canadian Wildlife Service, Aylmer District, for accommodations at Big Creek Station. This research was funded by Environment and Climate Change Canada and the Natural Sciences and Engineering Research Council of Canada. All procedures with the animals were done with the approval of the Canadian Wildlife Service of Environment Canada and the Ontario Ministry of Natural Resources and complied with McGill University Animal Use Protocol 4569.

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The observed decline of Western Toads (*Anaxyrus boreas*) over several decades at a novel winter breeding site

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Abstract

The Western Toad (*Anaxyrus boreas*) population of the Atlin Warm Springs in northwestern British Columbia has persisted since at least 1924. An extraordinary feature of the population has been winter breeding in late February to early March, while nearby cold-water populations breed in late-May. Metamorphosis of tadpoles, enhanced by the warm water, occurs as early as late-March. In 2008, Amphibian Chytrid Fungus (*Batrachochytrium dendrobatidis*) was documented in toadlets at the warm springs. Until 2005, as many as eight egg clutches and 25 breeding adults had been observed at the warm springs, after which the population declined. In 2017, novel spring breeding occurred in a cooler pond in the spring complex. Future observations will help determine whether the population is recovering and whether breeding phenology and habitat use have changed.

Key words: Amphibian Chytrid Fungus; *Anaxyrus boreas*; *Batrachochytrium dendrobatidis*; breeding population; breeding habitat; northwestern British Columbia; Western Toad; warm springs

Introduction

Since at least 1924, the Western Toad (*Anaxyrus boreas*) population of the Atlin Warm Springs has received substantial attention from biologists and naturalists, inspired by the relatively dense population that bred in a small and discrete habitat near the town of Atlin, British Columbia. The population occurs at the most northerly latitude of the species' range (Matsuda *et al.* 2006; Slough and Mennell 2006; Slough 2013). Cook (1977) collated some of the records of Western Toads from Yukon and northern British Columbia, and Slough (2009) summarized additional observations and specimens collected from 1924 to 2009. Additional observations to 2012 were contributed by B.G.S. to the COSEWIC assessment and status report on the Western Toad, Non-calling population (COSEWIC 2012). An unusual feature of the warm springs population was that breeding occurred in late February through early March, while adjacent cold-water populations congregated to breed in a 2-week period from late May through early June after ice breakup (Slough and Mennell 2006).

Local residents of Atlin and Whitehorse have traditionally observed toadlets at the springs over the Easter holidays (i.e., shortly after the vernal equinox on 21 March). Early breeding, in late March, has also been reported for Western Toad populations at warm springs in Utah (Thompson 2004). Some toads in Utah did not hibernate and were active year-round. It is not known whether the toads of the Atlin Warm Springs hibernate or remain active in winter.

Methods

The Atlin Warm Springs is a cluster of geothermal springs that arise near Warm Bay on the east side of Atlin Lake in northwestern British Columbia (59.404°N, 133.575°W), 20 km south by southwest of the town of Atlin, and about 650 m from the lake (Figure 1). A second set of springs is located about 300 m to the west, and both drain into Atlin Lake. There are several underground sources of spring water, although most of the water emerges in three primary source pools. The largest source pool (≤10 m in diameter and 1 m deep) and several smaller pools (<0.5 m in depth), drain into a common stream. The largest pool was mechanically excavated for bathing.

The water is clear and odourless. Water temperature is 29°C at the large source pool, with pool and drainage stream temperatures 23–27°C at breeding sites in March and up to 29°C in summer. A single cooler spring-fed pond (15°C in winter) lies at a slightly lower elevation in the centre of the warm springs complex (spring 2017 breeding site in Figure 1). Shallow tufa (calcite) basins are present where the stream cascades downslope and runs underground for about 30 m. The tufa deposits are porous and may provide hibernacula, hiding places, and foraging habitat for Western Toads.

Annual growth of vegetation in the springs begins in March. Vegetation consists of green algae, Small Duckweed (*Lemna minor* L.) and introduced Small-leaved Watercress (*Nasturtium microphyllum* Boenninghausen ex Reichenbach). Lake Chub (*Couesius plumbeus*) in-

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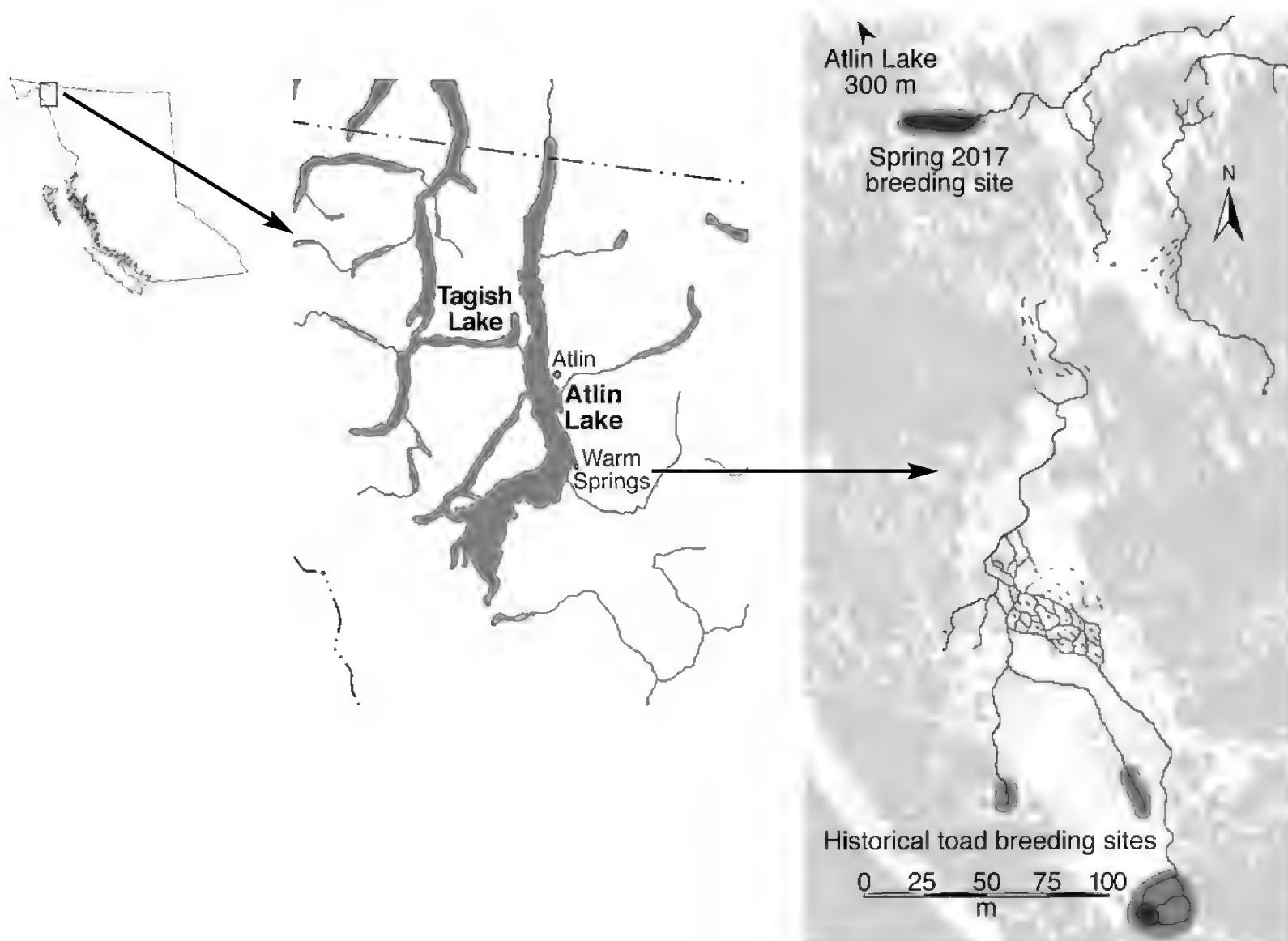


FIGURE 1. Atlin Warm Springs complex, northwestern British Columbia (59.404°N, 133.575°W), showing historical winter and 2017 spring breeding sites (grey shading). Breaks in streams indicate underground flow. Forest and meadows shown in background of spring complex with Imagery ©2018 DigitalGlobe, map data ©2018 Google.

habit the springs. We have observed Red Marshworm (*Lumbricus rubellus*), a potential prey of the Western Toad, to be abundant in the meadows surrounding the springs. Goldfish (*Carassius auratus*) were introduced to the western springs in about 2000 (S. Badhwar pers. comm. 11 March 2007), and Red Cherry Shrimp (*Neocaridina davidi*) were introduced to the eastern springs between October and December 2015 (A.dB. pers. obs.). Lake Chub and Red Cherry Shrimp are absent from the cooler pond.

Between 1996 and 2018, we searched for Western Toads in the Atlin Warm Springs using visual encounter surveys of the source springs, streams, and surrounding meadows (Table 1). The breeding sites and meadows encompassed about 1 ha and were surveyed in 1–2 h. Adults were rarely found far from water or outside of the breeding season. They may have dispersed from the site to other summer foraging habitats, or they may have gone underground into crevices created by the tufa. We also solicited observations from Environment Yukon and Environment Canada based out of Whitehorse. In addition, observations were made by A.dB. during a study of Lake Chub and Cherry Shrimp in 2017.

Results

Numerous observations of Western Toads at the Atlin Warm Springs from 1924 through 2005 indicate that a healthy breeding population persisted for at least 80 years (Table 1). After 2005, breeding activity and sightings of adults became sporadic, suggesting a population decline. Amphibian Chytrid Fungus (*Batrachochytrium dendrobatidis* [Bd]) was detected on Western Toad juveniles and adults from adjacent Atlin Lake in 2007 and on toadlets from the warm springs in 2008 (Slough 2009). Since 2005, observations have consisted of two clutches of eggs in 2008, one toadlet and one adult in 2012, and one toadlet in 2014. There has been no other evidence of breeding at the historical breeding sites within the springs in other years between 2006 and 2018. Three dead adult Western Toads were found in or near the springs on 7 March 2005, where at least four aggregations of recently hatched tadpoles were present. There was no obvious trauma to the dead toads.

Breeding behaviour, involving ≥ 25 adults and ≥ 8 egg clutches, was observed between 7 and 22 March in five years between 1998 and 2005 (Figure 2). Records of newly hatched larvae suggest that oviposition occurred during or before 4–10 March. Larvae that were

TABLE 1. Western Toad (*Anaxyrus boreas*) observations at the Atlin Warm Springs, northwestern British Columbia (59.404°N, 133.575°W), 1996–2018. Larval stages after Gosner (1960). Absence of data for some years indicate that the site was not visited.

Date	Eggs	Tadpoles	Terrestrial stages
Early April 1996	0	Numerous	0
22 March 1998	0	Wide range of stages (26–45), from early to near metamorphosis	0
12 February 1999	0	0	0
13 March 1999	≥8 clutches	Newly hatched (stage 20)	1 dead yearling; ≥6 adults, including 4 calling males and spawned female
9 March 2001	0	Early to mid-stages (20–30+)	≥25 breeding in 4 areas
7 March 2005	0	≥4 recently hatched aggregations (stage 26+)	1 male and 3 dead adults (1 frozen on land, 2 in stream)
21 March 2005	0	To stage 40	0
21 March, 3 June 2006	0	0	0
12 March, 19 April 2007	0	0	0
10 March 2008	0	~ 500 tadpoles (stages 26–30). Estimated: 2 clutches	0
10 May 2008	0	0	100s metamorphs (stages 44–46)
27 April 2009	0	0	0
6 April 2010	0	0	0
15 March, 2 July 2011	0	0	0
12 August 2012	0	0	1 adult, 1 toadlet (S. Stotyn, S. Cannings)
18 March 2013	0	0	0
28 June 2014	0	0	1 toadlet (S. Stotyn, S. Cannings)
20 June 2016	0	0	0 (S. Stotyn, S. Cannings)
16 May 2017	0	0	0 (J. Hobbs)
17 June 2017	0	3 aggregations, possibly from one egg clutch, downstream from traditional breeding sites	2 adults (A.dB., E. Titley)
25 February, 31 March, 27 May 2018	0	0	0 (B.G.S., A.dB.)

Sources: Observations by B.G.S. unless noted. Presence/absence data to 2012 were previously presented by Slough (2009) and COSEWIC (2012).

near metamorphosis (stage 45; Gosner 1960) observed on 22 March 1998 placed oviposition in mid-February using developmental times of Olson (2005). However, development may be more rapid in the warm water of the springs compared with cold-water habitats, as egg and tadpole development are largely temperature dependent (Matsuda *et al.* 2006). Western Toad eggs reportedly hatch within 3–12 days (Olson 2005) or 7–10 days (Matsuda *et al.* 2006) across the species’ range. Goettl (unpubl. data 1996 as cited in Loeffler 2001) reported Western Toad eggs hatching in 5–7 days at 19°C with completion of metamorphosis 45 days post-breeding in the Southern Rocky Mountain population. Maxell *et al.* (2002) have reported time to hatching of ≤7 days in Montana, with metamorphosis ≤42–49 days post-oviposition. Metamorphosis may take up to three months in some systems (Olson 2005).

At least three clusters of tadpoles (possibly from one egg clutch) were observed at the only cooler pond within the Atlin Warm Springs complex on 17 June 2017, long after the late March to early April metamorphosis,

which follows winter breeding (Figure 2). The tadpoles were not handled on site, but, from photographs, they appear to be at Gosner stage ≥30, indicating breeding in late May, as is typical for regional cold-water populations. Two adults were observed in terrestrial meadow habitat adjacent to the historical warm springs breeding habitat.

Discussion

Batrachochytrium dendrobatidis must be considered a factor contributing to the local population decline of Western Toads observed from 2006 to 2018. The fungus causes the infectious disease chytridiomycosis, a global threat to Western Toads across the range of the species (summarized in COSEWIC 2012). Water temperatures in the warm springs (average of 26°C in winter) are near the thermal maximum for *Bd* growth (26–28°C; Stevenson *et al.* 2013); however, the thermal tolerance of *Bd* strains is variable and the fungus is known to be adaptable to temperature conditions (Voyles *et al.* 2017). A temperate strain of *Bd* from

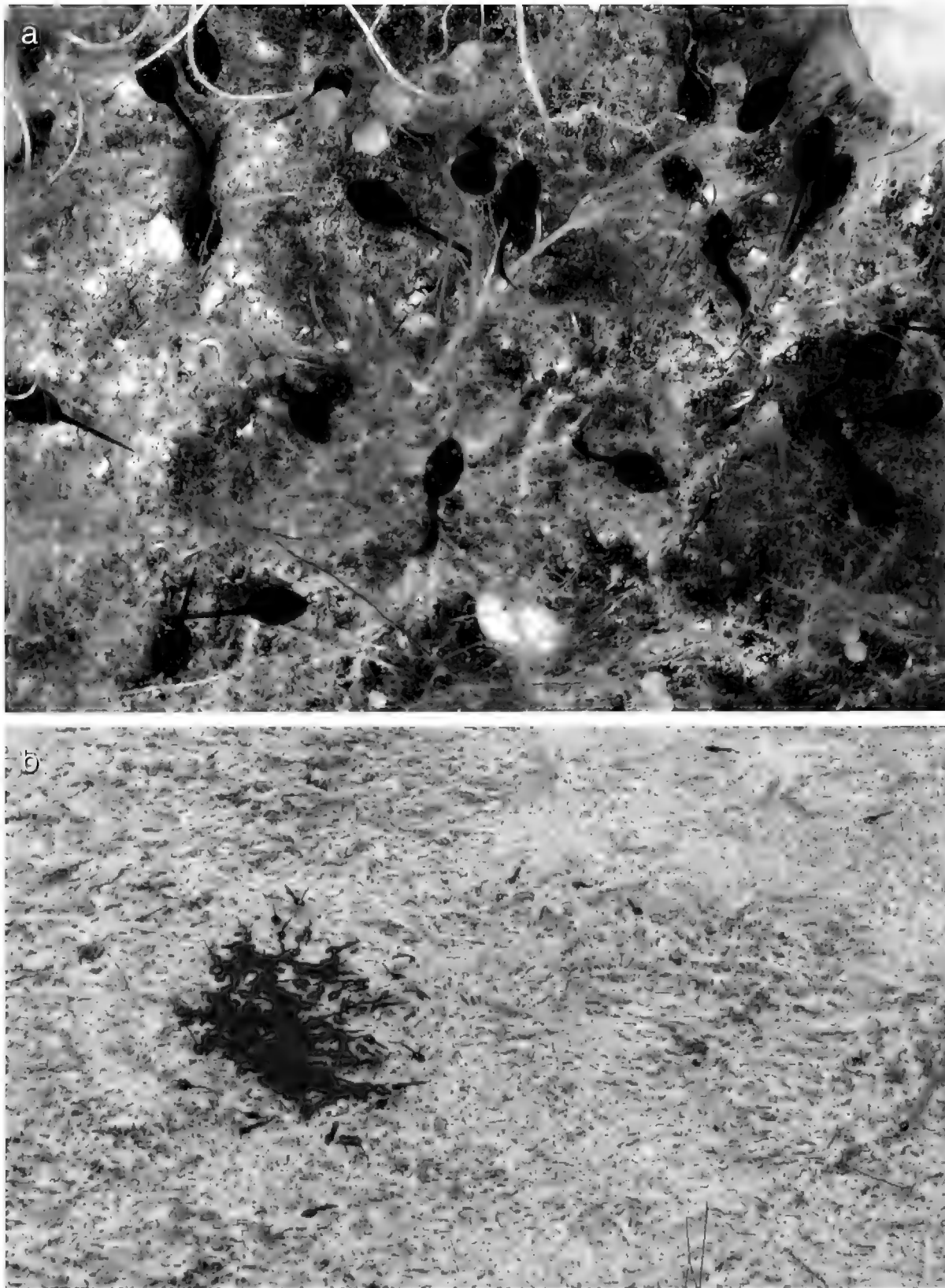


FIGURE 2. Western Toad (*Anaxyrus boreas*) tadpoles in the Atlin Warm Springs, northwestern British Columbia (59.404°N, 133.575°W), on 7 March 2005 (a) and 17 June 2017 (b). Photos: B. Slough (a) and A. deBruyn (b).

California grew well at 2–27°C and following freeze and heat shock treatments (Voyles *et al.* 2017). The Atlin Warm Springs are not likely a refuge from *Bd*.

The recovery of the Western Toad population of the Atlin Warm Springs may be limited by life cycle and reproduction. Females mature at 4–6 years of age, and most breed only once in their lifetime (summarized in COSEWIC 2012).

Climate change and severe weather are expected to have a low impact on Western Toad populations in British Columbia (Environment and Climate Change Canada 2016), although the predicted increase and frequency of droughts may threaten small wetland breeding sites and micro-sites used for rehydration (Provincial Western Toad Working Group 2011). Climate

warming is expected to affect the phenology of breeding, larval development, and hibernation. In 2005, a single stochastic cold weather event during breeding did not appear to be the cause of mortalities and the subsequent population decline. In fact, March 2005 was relatively mild: daily mean -1.1°C , versus a long-term mean of -5.5°C for 1981 to 2010 (Environment and Climate Change Canada 2018; data from Atlin, British Columbia weather station, 20 km north-northwest of the Atlin Warm Springs). Nonetheless, activity during freezing temperatures, such as movements from hibernacula to breeding sites, places Western Toad at risk of exposure.

Amphibians including Western Toads are known to exhibit adaptive responses to climate change, such as

adjusting breeding phenology in response to warmer temperatures (Blaustein *et al.* 2001; Urban *et al.* 2014). Other plastic responses include enlarged clutch size, more rapid growth and development rate, and increased survival. This plasticity is possibly shared by the Atlin Warm Springs population of Western Toads.

We can only speculate on the cause of the novel spring and cool-water breeding observed in 2017. Was the warm springs Western Toad population extirpated and re-colonized by individuals with cold-water breeding patterns and habitat preference, or did surviving toads switch phenology and habitat in response to unknown factors in the warm springs? Western Toad tadpoles were observed at four sites on Atlin Lake in 2017 (Hobbs 2018), where the population appears healthy. The aggregating behaviour of cold-water tadpoles along shallow shorelines, where the water is sun-warmed, has not been observed at the warm springs.

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Note

The use of an anthropogenic structure by Eastern Red-backed Salamander (*Plethodon cinereus*)

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Abstract

Eastern Red-backed Salamanders (*Plethodon cinereus*) are abundant in much of eastern North America. Although they typically live on the forest floor, individuals may venture off the ground while foraging. An adult salamander was observed using a backcountry privy as cover; after being displaced, it returned to the original location within 9 h. Furthermore, the salamander scaled a 50-cm vertical height to return to that location. The salamander may have been using the privy as part of its territory and feeding on flies attracted by the faecal matter inside.

Key words: Eastern Red-backed Salamander; *Plethodon cinereus*; homing; climbing; foraging; territoriality; Algonquin Provincial Park; Ontario

Lungless salamanders (Plethodontidae) are a diverse group of small forest- and stream-dwelling salamanders (Petranka 1998). Most species are strongly associated with forest floor habitats and cover, such as rocks and woody debris. Cover provides foraging opportunities and moist refuges that prevent evaporative water loss from the body (Spotila 1972; Jaeger 1980; Feder and Londos 1984).

Eastern Red-backed Salamander (*Plethodon cinereus*) is a common salamander in eastern North America and has been the subject of numerous ecological studies (reviewed by Petranka 1998 and Anthony and Pfungsten 2013). Jaeger *et al.* (1993) note its homing behaviour after being displaced, and many authors have documented its ability to climb (Jaeger 1978; reviewed in McEntire 2016). Here, I present an observation of a single Eastern Red-backed Salamander that used artificial cover, quickly returned to the location after being displaced, and climbed a vertical wooden surface to do so.

On the morning of 15 July 2017, I arrived on a small island in McCraney Lake, Algonquin Provincial Park, McCraney Township, Ontario (45°33'N, 78°61'W) to camp for the night. The maximum daily air temperature was 26°C (minimum 14°C, mean 20°C). Of the 15 days leading up to the observation, precipitation fell on 10 days for a total of 55.6 mm, recorded at the weather station located at the East Gate of Algonquin Provincial Park (near Whitney, Ontario), ~50 km away (Environment Canada 2017). After inspecting the campsite, I proceeded to locate the privy, about 20 m away. At 1130 I lifted the lid and observed an adult Eastern Red-backed Salamander sheltering under the lid where the wood was in close contact with the seat. I moved the salamander to the forest floor, 1.5 m away. The following morning, at 0840, I returned to the privy to find that the salamander had returned to its exact original location.

The salamander was an adult, of the red-striped morph (Figure 1). I did not measure the snout-to-vent length or determine sex. I compared photos of the salamander from both days and used the pattern of small white head spots and markings on the tail to confirm that it was the same individual. Several slugs (Dusky Arion, *Arion subfuscus/fuscus* (Draparnaud, 1805)) and many flies were also found under the privy lid.

An Algonquin Provincial Park backcountry privy measures 82.5 cm (length) by 61 cm (width) by 51 cm (height), and has a hinged lid to allow the user to open and close it. The privy is constructed of Eastern White Cedar (*Thuja occidentalis* L.). Park maintenance crews inspect and repair privies regularly, and this unit was in good condition. No vegetation, sticks, or branches were touching the privy and, therefore, not aiding the salamander's climb.

Eastern Red-backed Salamanders have a relatively small home area, typically 0.16–0.33 m² (Petranka 1998). In addition, they have a well-developed homing ability; when moved distances of 30 m most individuals are able to return, some even over distances of 90 m (Jaeger *et al.* 1993). Therefore, it is not surprising that the salamander was able to quickly (within 9 h, and presumably less time, if activity is largely nocturnal) find its way back to its shelter; however, it also had to climb the vertical surface (51 cm) of the exterior of the privy.

Many lungless salamanders can make use of arboreal habitats and will climb vegetation and rock faces (McEntire 2016). Opportunistically, arboreal species, such as Eastern Red-backed Salamander, climb vegetation for several reasons. For example, Eastern Red-backed Salamanders that climbed vegetation had more food and larger prey items in their stomachs compared with those found foraging on the ground, suggesting

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FIGURE 1. a. Algonquin Provincial Park backcountry privy with open lid. Note the Eastern Red-backed Salamander (*Plethodon cinereus*) found under the lid (arrow) returned to this location, after being moved the previous day. b. Close-up of *P. cinereus* as found. The salamander was taking cover under the lid and possibly feeding on the abundance of small flies. 15 July 2017, Algonquin Provincial Park, Ontario. Photos: D. LeGros.

that climbing offers better foraging opportunities (Jaeger 1978). Salamanders may also climb vegetation to reduce predation risk or avoid dominant conspecifics on the ground (Roberts and Liebgold 2008). Although the extent of arboreal habitat use by temperate plethodontid salamanders is not well known, a growing body of work suggests that many species are using vertical habitats, such as plants, trees, and rock faces, more often than previously thought (McEntire 2016). Arboreal activity, like surface activity, in lungless salamanders is linked with wet conditions (LeGros 2013; McEntire 2016). Although the list of species and types of climbing continues to grow, little information is available regarding salamanders climbing human-made structures.

Adult Eastern Red-backed Salamanders are highly territorial and will aggressively defend territories from conspecifics to maintain access to quality food sources and mates (Jaeger 1982a; Jaeger and Forester 1993; Mathis *et al.* 1995; Petranksa 1998). As the salamander in this observation was found under the privy lid during the day and quickly returned after being displaced, it likely included this cover as part of its territory (Mathis *et al.* 1995).

This observation is unique because the salamander established a territory 50 cm above ground, under artificial cover, which may have provided regular access to prey. An abundance of small flies emerged from the opened lid of the privy, most likely attracted to the human faecal matter contained inside. Although none of the flies was collected or identified, they were small and easily consumed by salamanders.

Dipterans are consumed by Eastern Red-backed Salamanders (Petranksa 1998) and may make up as much as 10% of the diet of wild individuals (Jaeger unpubl. data, as cited in Jaeger and Barnard 1981). Eastern Red-backed Salamanders are capable of assessing prey quality and density and learn to forage optimally. In the laboratory, salamanders will use different foraging strategies when presented with low and high densities of two species of flies: for example, specializing in larger flies and ambushing them, rather than indiscriminately pursuing smaller flies (Jaeger and Barnard 1981; Jaeger *et al.* 1982b). Although it appears possible for Eastern Red-backed Salamanders to learn to take advantage of prey in high densities, they are not efficient patch foragers (Hill *et al.* 1982). Structurally simple environments with few obstacles and cover, such as the seat surface of the privy, improve the ability

of the salamander to locate prey (Jaeger and Barnard 1981).

Although plethodontid diversity may be high in some regions of Appalachia, in central Ontario, Eastern Red-backed Salamander is the only representative of its genus (Petranka 1998). The lack of species diversity may allow this salamander the opportunity to expand its ecological niche in this region. In addition, the presence of privies throughout Algonquin and other provincial parks that offer backcountry camping opportunities may serve as an unintentional resource that concentrates invertebrate prey that feed on randomly distributed resources like dung. There are approximately 1900 similar privies located throughout Algonquin Provincial Park. According to several backcountry staff, who have checked thousands of privies over a span of many years, none has ever noted a salamander under the lid (three Algonquin Provincial Park staff members pers. comm. 11 November 2017). Although Eastern Red-backed Salamanders will defend a territory to access prey and mates, if the cover object is disturbed frequently, they may abandon the territory (Marsh and Goicochea 2003); thus, it is likely that salamanders do not occupy privies at regularly used campsites. Despite the lack of observations, privies could be a significant source of concentrated foraging opportunities for salamanders and other predators of insects.

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Observations of Mudpuppy (*Necturus maculosus*) bycatch in a recreational ice fishery in northern Ontario

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Abstract

Bycatch in fisheries is a well-explored topic, although less so in recreational fisheries. We encountered frequent bycatch of Mudpuppy (*Necturus maculosus*), a neotenic aquatic salamander that is active in winter, in passively baited ice-fishing gear targeting teleost fishes. We noted hook location in Mudpuppies captured by two hook types: J-hooks and circle hooks. Our prediction was that circle hooks would reduce the frequency of deep hooking of Mudpuppies, which is often cited as an important predictor of post-release mortality in fishes. We found no difference in the frequency of deep hooking of Mudpuppies captured by circle or J-hooks, although, in a subset of Mudpuppies ($n = 13$) held for 24 h after capture, one death occurred (8%). Further research may be necessary to determine whether deeply hooked Mudpuppies can pass or shed hooks and survive beyond the 24-h period we monitored. However, our findings suggest that anglers and managers should consider refinements to handling practices for Mudpuppies captured as bycatch, because they are likely to survive if handled cautiously. These results, which are among the first describing non-fish bycatch in recreational fisheries, call for managers and anglers who encounter Mudpuppies during recreational fishing to seek more information and educational opportunities to improve the fate of this important component of temperate freshwater ecosystems and ecological indicator species that is incidentally captured by ice fishing.

Key words: Mudpuppy; *Necturus maculosus*; fisheries management; winter biology; circle hook

Introduction

In many nations, recreational fisheries are more economically valuable than the commercial sector, with billions of fish captured annually by recreational angling (Cooke and Cowx 2004; Tufts *et al.* 2015). The methods used to target fish in recreational fisheries tend to be more limited than in commercial fisheries, as fishing is predominantly conducted by hook and line with various lures, flies, or baits used to attract fish to hooks. Although the gear selected by anglers is often chosen to suit a specific target species or group of species (Pope *et al.* 2016), the incidental bycatch of non-target fishes can be considerable, as is the potential for capture of non-target taxa. Freshwater bycatch is an emerging conservation challenge (Raby *et al.* 2011; Stoot *et al.* 2013), although the literature has been focussed predominantly on commercial fishing (e.g., Silva and Best 1996; Bell and Lyle 2016).

Little research has been carried out on ice fishing, a type of recreational fishery popular at higher latitudes (Deroba *et al.* 2007; Twardek *et al.* 2018). Ice fishing involves drilling or cutting through ice to gain access to winter-active fish. Typically, a hook is baited with live or cut bait and set using rod or passive lines at an appro-

priate depth for the targetted game fish. Most jurisdictions allow for more than one line per angler at any one time and this, combined with water conditions and hole size, make observation difficult, hindering angler-mediated selectivity.

Understanding the impact of fishing practices on captured species is necessary to achieve sustainable fisheries. Best practices in recreational fisheries can be implemented to minimize impacts on captured animals (Brownscombe *et al.* 2017). This includes appropriate selection of terminal tackle (i.e., hooks), which is often regulated by management authorities (Schill and Scarpella 1997; Cerdà *et al.* 2010). Circle hooks have been marketed as an effective tool for reducing mortality of captured fish by minimizing deep-hooking (Serafy *et al.* 2012). The circle hook is designed with the point oriented 90° to the shank so that it rotates when ingested by an animal and lodges more frequently in the lips rather than the gullet. Circle hooks are used in both commercial and recreational fisheries to minimize bycatch of non-target fish as well as other taxa such as marine turtles (Cooke and Suski 2004; Sales *et al.* 2010).

Mudpuppy (*Necturus maculosus*) is a species of neotenic freshwater salamander native to North American

lakes and rivers. Mudpuppy activity is highest in cold temperatures, and they feed on many of the same prey items as game fish (Shoop and Gunning 1967; Beattie *et al.* 2017). Although not listed as at risk in most jurisdictions, including Canada (SARA Registry 2018), declines in population levels have been reported (Mifsud 2014; Harding and Mifsud 2017), and several United States agencies have granted them various conservation statuses (Matson 2005). Mudpuppies are long-lived (Bonin *et al.* 1995) and late to mature (Bishop 1943), likely making them sensitive to adult mortality (Congdon *et al.* 1994). Siltation and chemical pollutants (Bonin *et al.* 1995; Matson 1998, 2005) are likely chronic threats to local populations, and bycatch in recreational ice fisheries is a recognized but poorly quantified risk.

Capture of Mudpuppies by ice fishing is incidental in the winter, when Walleye (*Sander vitreus*) and other teleosts are targetted with baited hooks, often on passively set lines near the substrate where Mudpuppies are most active (Craig *et al.* 2015). Mudpuppies may ingest hooks on set lines, resulting in deep-hooking, a topic that has been extensively explored for teleost species and consistently demonstrated to be one of the most important predictors of post-release mortality in recreational catch-and-release fisheries (Muoneke and Childress 1994). Although Mudpuppies may be captured by recreational anglers, their presence in lakes may not be well known among anglers, and some anglers may cull them out of spite or misunderstanding of their ecological role (Craig *et al.* 2015). Retrieval, handling, unhooking, and release of Mudpuppies may be inconsistent among anglers with a poor understanding of the species biology, particularly without guidelines regarding best practices. Moreover, it is uncertain whether Mudpuppies captured and released through ice holes are likely to survive or if the retrieval, exposure to air and cold, handling, or hooking damage will lead to mortality.

In this study, we compare the hooking of Mudpuppies captured on two terminal hooking gears, circle hooks and J-hooks, and quantify the short-term survival of Mudpuppies released following recreational angling.

Methods

Mudpuppies were captured as bycatch (Figure 1) between 2100 and 0700 while fishing for Walleye on South Bay, Lake Nipissing, Ontario, Canada (46.2730°N, 79.8022°W). Between 10 January and 3 February 2017, we set passive lines using tip-ups, which have a spring-loaded mechanism for signalling the hooking of a fish that has struck a baited hook passively suspended beneath the ice. The sensitivity of these devices is set to detect the presence of larger teleost fishes that pull on the spool with more force than Mudpuppies; thus, the reliability of the flag signal to detect Mudpuppies was poor. Tip-ups were set 15–30 cm off bottom (depth

~7–8 m) with both circle and J-style hooks (Octopus 4 and Octopus circle 4; Gamakatsu, Tacoma, Washington, USA) baited with live shiners (e.g., *Notropis* spp.) and weighted with a 7-g lead sinker. Water temperature remained at 4°C in the hypolimnion layer where Mudpuppies were captured, while ambient air temperature varied from –19.4°C to 3.3°C during the study period.

Mudpuppies were landed by angling in approximately 20 s, with little variation among individuals. For each Mudpuppy that was captured, we estimated the length (to the nearest centimetre) and characterized the anatomical hooking location. Following practices of local anglers who captured Mudpuppies, we removed the hooks from individuals hooked in the lip and cut the lines on all deeply hooked Mudpuppies. The observation period resulted in about 45 s of air exposure. A subset of 13 Mudpuppies was transferred into conical holding pens (volume = 0.5 m³) suspended beneath the ice at the depth at which the Mudpuppies were captured (~7–8 m). Nets were emptied after 24 h to determine Mudpuppy survival. No net held more than three Mudpuppies during an overnight holding period.

Because of this small sample size, statistical analysis was not feasible to determine drivers of mortality; thus, we simply provide accounts of the mortality. A χ^2 test was used to evaluate potential differences in hooking locations of Mudpuppies caught by circle and J-style hooks using the `chisq.test` function in R (R Core Team 2017).

Results

During an estimated 3655 rod-h on Lake Nipissing using both passive and active lines, we captured 80 Mudpuppies, ~0.02/rod-h. Although not quantified, most Mudpuppies were captured at night and on passive baited lines. For our study, we captured 48 Mudpuppies on passively set ice fishing lines. One of these was captured by a dead-stick (i.e., ice fishing rod passively suspending a baited lure) with a treble hook and was excluded from further description because of low sample size with this gear; however, this individual was hooked in the outer lip and survived. We were unable to measure most Mudpuppies because they responded to capture and handling by curling into a small ball. However, we estimate that most were ~18–22 cm long. At these sizes, they are not likely to be fully mature (McDaniel *et al.* 2009).

Only four of the 47 Mudpuppies (9%) were shallow hooked in the lips; the remainder had ingested the baited hook, which we assumed was lodged inside the stomach (Figure 2). There was no difference in the incidence of deep hooking with circle hooks compared with J-hooks ($\chi^2_1 < 0.01$, $P = 1.00$). Despite the high frequency of deep hooking, only one of 13 Mudpuppies died (8%) during the 24-h holding. This individual was captured using a circle hook and ingested the hook. All other Mudpuppies were released back into the water.



FIGURE 1. Mudpuppy (*Necturus maculosus*) captured by ice fishing in Lake Nipissing, Ontario, Canada. This individual was not included in the study, but is representative of the type of capture event investigated. Photo: W.M. Twardek.

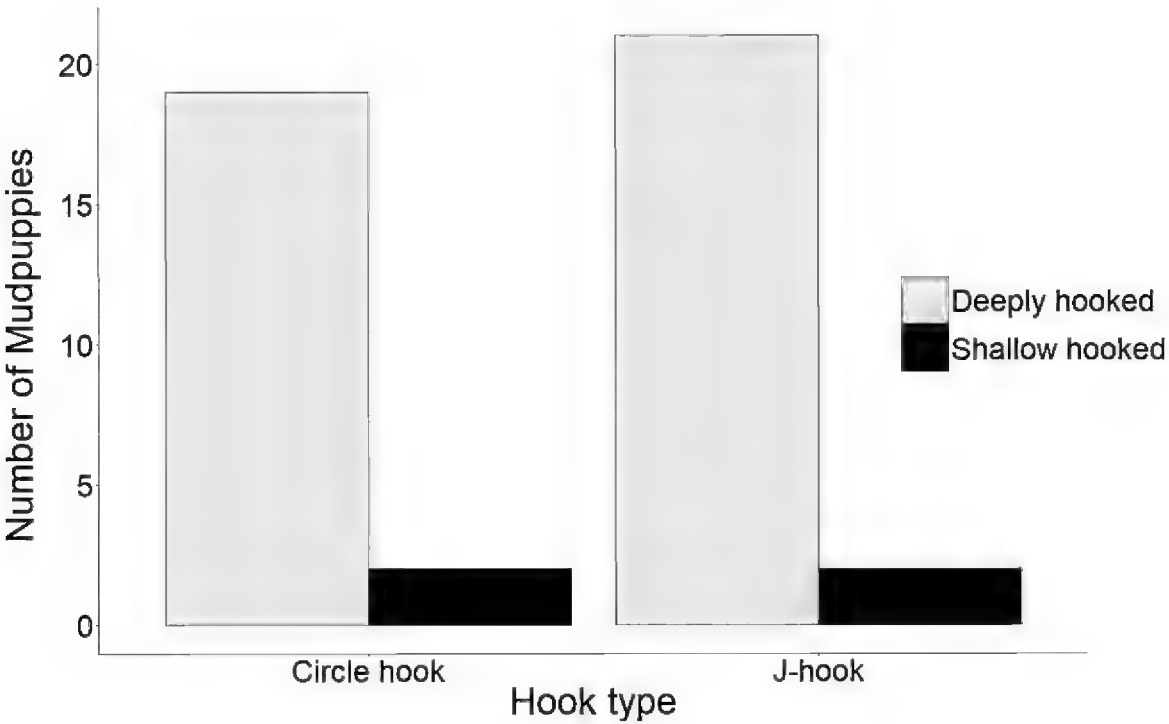


FIGURE 2. Hooking locations, characterized visually, and hook types observed to capture Mudpuppies (*Necturus maculosus*) while ice fishing in Lake Nipissing, Ontario, Canada.

Discussion

This was an opportunistic study of Mudpuppies conducted during an ice fishing project targeting Walleye, and sample sizes were small. However, it is clear that a large number of Mudpuppies may be captured and released by recreational anglers in winter ice fisheries. Our findings present the first evidence that Mudpuppies survive encounters with recreational anglers even when deeply hooked and call for additional research on the extent and impact of recreational bycatch of Mudpuppies.

Encounters with anglers in the fishery suggested that they were unfamiliar with Mudpuppies and unaware of their presence in Lake Nipissing, which is a prominent ice fishing destination. We observed some anglers capturing Mudpuppies and jettisoning them onto the ice to inspect them before we suggested that they cut the line and release them down the hole. We did not study the effect of prolonged exposure to sub-zero air temperatures, but given that Mudpuppies respire by lungs, gills, and through the epithelium, these external organs (gills and skin) may be sensitive to freezing temperatures and the formation of ice crystals on these structures could cause permanent damage. Additional research is necessary to determine the effect of cold air exposure, but presumably the most risk-averse and recommended behaviour would be for anglers to rapidly unhook (or cut) Mudpuppies from the line and release them back into the water with limited air exposure. This is consistent with guidelines for fish captured either incidentally or intentionally that are destined to be released (Cook *et al.* 2015), but could be more urgent at lower temperatures.

Relative to most fish captured by hook and line, the observed rates of deep hooking in Mudpuppies were high (Hühn and Arlinghaus 2011). This is likely related to the feeding ecology of Mudpuppies that use interlocked lips to suction-feed on prey (Gans and Nussbaum 1992). Some anglers targeting Walleye or other teleosts may insist on removing hooks from deeply hooked Mudpuppies; however, evidence from teleosts consistently suggests that hook removal from deeply hooked animals results in organ injury and bleeding, whereas cutting the line may allow the animal to pass or shed the hook (e.g., Weltersbach *et al.* 2016). Although we did not experiment with different hook removal techniques, our results suggest that cutting the line and releasing deeply hooked Mudpuppies results in infrequent short-term mortality. Further research may investigate whether survival is significantly different for hook removal compared with cutting the line. However, removing the hook from a deeply hooked Mudpuppy would most likely be fatal; thus, we only ever cut the line. Whether Mudpuppies can successfully expel a hook could be further studied using longer-term observations of survival or radiography (see Weltersbach *et al.* 2016).

In this study, we found that circle hooks did not reduce the frequency of deep-hooking Mudpuppies and, therefore, are not necessarily an effective means of improving the fate of Mudpuppies captured by anglers. However, larger sized hooks may preclude swallowing by Mudpuppies and their potential could be further investigated alongside a Walleye fishery to compare catch rates of Walleye and critical hooking rates of Mudpuppy. Observed high rates of deep-hooking are likely similar to those naturally occurring in the fishery but may be because of low sensitivity of the tip-ups, which were calibrated for detecting bites from Walleye.

Mudpuppies are an important component of freshwater ecosystems and are long-lived and late maturing, life history traits that make them vulnerable to over-exploitation as bycatch in recreational fisheries (Matson 2005; Craig *et al.* 2015). Their presence in freshwater systems is a good indicator of ecosystem health (Craig *et al.* 2015), and their conservation should be a priority for those who work for natural resource management agencies, including fisheries managers, to ensure that they are covered in fishing regulations. Given that we frequently captured Mudpuppies while fishing for Walleye, a better understanding of the responses of Mudpuppies to angling may be necessary to provide recommendations to anglers who capture them, dispel myths about their negative interactions with gamefishes, and promote best handling practices so that Mudpuppies can be released from ice fisheries alive (Craig *et al.* 2015).

Author Contributions

Writing – Original Draft: R.J.L., W.M.T.; Writing – Review & Editing: R.J.L., W.M.T., S.J.C.; Conceptualization: R.J.L., W.M.T., S.J.C.; Investigation: R.J.L., W.M.T.; Methodology: R.J.L., W.M.T.; Formal Analysis: R.J.L.; Funding Acquisition: S.J.C.

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Book Reviews

Book Review Editor's Note: *The Canadian Field-Naturalist* is a peer-reviewed scientific journal publishing papers on ecology, behaviour, taxonomy, conservation, and other topics relevant to Canadian natural history. In line with this mandate, we review books with a Canadian connection, including those on any species (native or non-native) that inhabits Canada, as well as books covering topics of global relevance, including climate change, biodiversity, species extinction, habitat loss, evolution, and field research experiences.

Currency Codes: CAD Canadian Dollars, USD US Dollars, EUR Euros, AUD Australian Dollars, GBP British Pound.

BOTANY

Catalogue of the Vascular Plants of New York State, Memoirs of the Torrey Botanical Society, Volume 27

By David Werier. 2017. Torrey Botanical Society, New York Botanical Gardens. 542 pages, 35.00 USD, Cloth or E-book.

David Werier's recent *Catalogue of the Vascular Plants of New York State* presents an extremely thorough revision of previous New York state lists, resting on at least two centuries of botanical exploration and documentation. The volume incorporates comprehensive taxonomic updates, reflecting the significant research that has resulted in revisions at the species, generic, and even family levels. Importantly, older synonyms are well-indexed, which is very helpful in these days of frequently changing nomenclature.

The catalogue is the result of extremely thorough herbarium research by Werier, who personally reviewed and confirmed specimens of all but 107 of the 3922 taxa reported for the state. Werier has undertaken a dedicated and even dogged correction of previous misidentifications. In addition to the list of accepted taxa, the catalogue also contains an updated list of excluded and (helpfully) expected taxa. Werier has painstakingly documented his methods including rationales for inclusion, exclusion, and the inevitable cases of doubt. Specimen and sometimes barcode numbers are cited directly. There is also extensive documentation of hybrids. I have yet to find anything absent from the index.

It is interesting that in a populous state as well-botanized as New York, 24 native species have been added to the flora since 2003 (not including changes in taxonomic concepts). Tellingly, the majority of recent additions to the New York flora are non-native. It is the attention to non-native species that presents the greatest innovation in this catalogue. Unusually, Werier includes not only naturalized but also "not-naturalized" species in this category, meaning that he includes even those species that are not believed to persist over winter. He has created a unique and fairly effective method of categorizing these taxa, providing baseline information on each taxon's first documentation in New York, which may well be extremely valuable in the years ahead.

At times, one might wish Werier were a bit less comprehensive in this regard, as the "not-naturalized" flora includes even single waifs collected around grist mills in the 19th century. About half of his 1585 documented non-native species are "not-naturalized" (i.e., not persistent), or their status is unknown. In groups with large numbers of introduced species (e.g., Poaceae), the inclusion of these can be somewhat distracting, and Werier admits that the vast majority have little influence on the ecology of natural areas. Some inclusions are even an amusing stretch (e.g., Avocado [*Persea americana*] collected "from new compost"). But to be comprehensive is a worthy goal, and such distractions will probably prove insignificant compared to the long-term value of this catalogue.

If I had a wish for this volume, it would be the inclusion of a bit more ecological information and a map on New York's physiographical or ecological regions in the introduction, in order to place the checklist in context. It would also be helpful to see brief information on the abundance and range of each taxon within the state. With the hardcover volume already totalling 542 pages, one understands that space was limited. Admittedly, the catalogue is intended to be used together with the excellent New York Flora Atlas website (<http://newyork.plantatlas.usf.edu>) to which it is linked, and where one can find range maps. A catalogue such as this can spur botanists to document lesser-known groups, and Werier strongly encourages this. It seems likely that new discoveries and further iterations of this edition will follow.

This catalogue will appeal most strongly to the professional or serious amateur botanist. For botanists in regions of Ontario and Quebec adjacent to New York State, it offers many attractions. Plants know no jurisdictional boundaries, and this work provides a quick reference to determine the presence and conservation status of species and hybrids just across the border. This can offer some interesting surprises. I have also been

using it as a quick hardcopy reference for its reliably current taxonomy and extensive inclusion of synonymy. Used with distribution maps of species in the online New York Flora Atlas, it can also point to species that are relatively common in New York, but which may be overlooked in adjacent areas north of the border. With its thorough inclusion of non-native species, it may

(alas) offer a bellwether of things to come. And, more positively, it presents a tantalizing list of southern rarities for the dedicated botanical tourist. New York botanists are fortunate to have such a resource for their state for the foreseeable future.

HOLLY BICKERTON

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Flora of Florida Volume 5 (Dicotyledons, Gisekiaceae through Boraginaceae)

By R.P. Wunderlin, B.F. Hansen, and A.R. Franck. 2018. University Press of Florida. 303 pages. 69.95 USD, Cloth.

With the publication of Volume V of the *Flora of Florida*, this monumental project is half way there. There was a long pause after the 2000 publication of the first part (*Flora of Florida Volume I, Pteridophytes and Gymnosperms*, University Press of Florida) but a flurry of production has seen Volumes II through V released in the last three years (see reviews of the earlier volumes in Canadian Field-Naturalist 130: 248–249, <https://doi.org/10.22621/cfn.v130i3.1890> and 131: 375–376, <https://doi.org/10.22621/cfn.v131i4.2090>). Two more volumes will need to be published to complete coverage of the pteridophytes, gymnosperms, and dicots. Then three more volumes treating monocots will still be required—so there is much ground to be covered yet. But with the half-way point reached, the authors' ambitious goal of having all ten volumes in print by 2020 may yet be achievable.

The vascular plant species of approximately 400 taxa in 34 families are treated here, including numerous species in major groups with northern components such as Ericaceae, Cornaceae, Rubiaceae, Sarraceniaceae, and Apocynaceae. The physical characteristics of each taxon presented in this sturdily bound, hard-cover book are described with precise but not overly technical terminology, presented in small but easily-readable type. This is particularly important because the text is unillustrated. Readers are encouraged to consult the on-line *Atlas of Florida Plants* (<http://florida.plantatlas.usf.edu>) for photos of most taxa and for more detailed range information than is provided by the adequate but brief summaries in the text. Nomenclatural detail is a strength of the *Flora of Florida* project in general and this volume is no different, with quite exhaustive synonymy being provided for many species. The 46 synonyms identified for Deerberry (*Vaccinium stamineum*) might be a record for any species treated so far!

As before, effective species identification keys, taken or updated from Wunderlin's *Guide to the Vascular Plants of Florida*, published in 1998 by University of Florida Press, are placed immediately after each genus description. Alphabetically arranged species treatments follow, each beginning with the aforementioned comprehensive synonym. The sheer number of rare and endemic taxa described in this volume dramatically underscores the remarkable biodiversity of Florida. Although there appear to be fewer subspecific taxa treated in Volume V than in earlier installments, the authors seem to strike a middle ground along the lumping-splitting spectrum. They do not accept recent fine splitting of some long-established and particularly complex taxa (e.g., *Opuntia humifusa*, p. 37). In most such cases at least, they explain their reasons for doing this and note alternative interpretations.

As with the other volumes, this treatment addresses many species that reach southern Canada and northern range limits seem to be reflected quite accurately for the most part. These treatments provide Canadian botanists with an interesting regional perspective and context “from away” which can be quite different from our own. The treatment of over two dozen species of milkweed (*Asclepias*; pp. 212–224), for example, puts the smaller Canadian diversity of that genus into startling perspective, to say nothing of discussions of over a dozen pitcher plant (*Sarracenia*) taxa (pp. 102–108).

Let us hope the momentum for completing the *Flora of Florida* holds up and the remaining five volumes are indeed released by the end of 2020. For now, however, we can appreciate and celebrate this latest excellent contribution towards that goal of enumerating and describing the vascular plants of one of the most floristically diverse parts of our continent.

DANIEL F. BRUNTON

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Islands of Grass

By Trevor Herriot. Photography by Branimir Gjetvaj. 2017. Coteau Books. 224 pages, 39.95 CAD/USD, Cloth.

If you have always wanted to explore Grasslands National Park (GNP) in southern Saskatchewan but haven't managed to pull that off yet, get this book to see why you have to move it to the top of your 'Must See' list. But if you have managed to navigate across the vast ocean of Canadian prairie grain fields to visit that remarkable landscape, you should also get this book to remind yourself why that long, big-sky drive was worth it. Either way, *Islands of Grass* offers an accurate, visually stunning, and verbally inspirational portrayal of GNP and its sister native grasslands across the northern Great Plains.

I refer to GNP and sister native grasslands as separate entities; sadly, that is all too true. Less than 20% of the original native prairie grassland remains and less than 4% of that is in protective status. While we are quick to disparage overdevelopment and history of abusive land use in more heavily populated forested landscapes, especially in the east, the native prairie of western Canada actually constitutes the most ecologically reduced and imperilled of all major Canadian biomes.

But let's get back to celebrating it, which *Islands of Grass* is all about. At first glance it is tempting to treat this small, well constructed, and full colour volume as a 'coffee table' book. And it is, though much more as well. Gjetvaj's images are routinely wonderful and frequently breathtaking. I've had the good fortune of visiting GNP on three (far-too-short) occasions and the take-away feeling from those visits is demonstrably reflected in these images. Capturing the depth and size of prairie landscape in a photograph is really tough, as my innumerable lifeless attempts to do so document only too well. Somehow Gjetvaj achieves an almost three-dimensional quality in many of his images. Scanning his landscape vistas in *Islands of Grass*, one can almost hear the meadowlarks singing.

And reading Herriot's text, you can almost smell the locoweed (*Oxytropis*), sagebrush (*Artemisia*), and dust—with perhaps a *soupçon* of bison poop! His words are as illustrative and evocative as the book's photography. This is not a traditional "natural history of..." book but, nonetheless, it contains an abundance of well researched (and referenced) information on the evolution, significance, and ecology of native grasslands. Its discursive presentation means that you have to dig a bit to pull it all together, but you will learn a lot about native grassland dynamics, even if you thought you already knew a good deal about the subject. Herriot delves deeply into how native grassland sounds and feels, into the magic of the place, and how it can provide a reasonably perceptive visitor with a better perspective on their place on this planet. It's quite remarkable, really.

Appropriately, the book is dedicated to the late George Ledingham. For decades he was the doggedly

determined inspiration for a grasslands national park. Herriot gives him full credit for his pivotal role and nicely captures the personality of this important resident of the grasslands. A pillar of the prairie naturalist community, Ledingham was elected an Honorary Member of the Ottawa Field-Naturalists' Club largely for his work towards the establishment of GNP (see Canadian Field-Naturalist 127: 76–81, <https://doi.org/10.22621/cfn.v127i1.1414>). It was disappointing and a bit surprising, however, not to see a photo of George in here, ideally out on the prairie, of course.

Islands of Grass employs insights into iconic prairie fauna such as American Bison (*Bison bison*), Black-tailed Prairie Dog (*Cynomys ludovicianus*), Kit Fox (*Vulpes macrotis*), sage grouse (*Centrocercus* sp.), and Burrowing Owl (*Athene cunicularia*) to describe and explain the nature, scope, and significance of change in this landscape. Not a lot of cheery news there, it must be said. Some, but not a lot. Accordingly, the conservation message is strong throughout the book. The ongoing important but currently losing battle to keep native prairie community pastures in public ownership, for example, receives considerable well-reasoned discussion and argument. It is not surprising to report that large scale agribusiness does not come off well in that discussion.

All this is expressed in Herriot's comfortable, unhurried, and discursive way, even if Chapter 5, "Possible Prairie", does seem to repeat the core conservation messages a bit too often. There is a tendency throughout to somewhat romanticize the conservation role of independent, multi-generational ranching and farming families, conclusions that seem a tad culturally biased.

Similarly, I don't think a negative word is expressed regarding Aboriginal activities, historic or contemporary, in regards to prairie land use or cultural attitudes. One need only to visit the remarkable Head-Smashed-In Buffalo Jump World Heritage Site in Alberta (another insightful place concerning the natural and human history of the Canadian prairies), however, to appreciate that land management by prairie people has always been directed by what was seen to be in their own best interest. Just like people everywhere. I would have liked to see the message more strongly expressed that effective conservation in the grasslands (or anywhere) is not driven by cultural affiliations or altruism but is fundamentally grounded in enlightened self-interest.

My favourite line in the book has got to be "whether you are a microbe or a buffalo, all flesh is grass" (p. 31). That pretty much makes the point, doesn't it? It all comes back to the grass, both in the prairie and in this informative and inspiring book.

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ENTOMOLOGY

Lady Beetles of the Northwest Territories

By Environment and Natural Resources. 2018. Government of the Northwest Territories. 75 pages, freely available (contact 867-767-9237 or NWTBUGS@GOV.NT.CA), PDF.

The best things in life are free—and sometimes they come from a government. In a world where we frequently speak of including and engaging people, we are pleased to see good examples of these actions. This book is an outstanding example. Although based on a deep analysis of scientific information, it can be used by both kids and scientists as a current and reliable source. And yes, it does include all 33 species of lady beetles (Family Coccinellidae) known to occur in the Northwest Territories (NWT).

Lady beetles are popular, not just because they are mostly attractive and friendly, but also because of their reputation for controlling garden pests. One of the major events in Inuvik every year (attended by the town's children and their parents) is the release of boxes of hundreds of lady beetles in spring to control pests (and avoid pest control using poisonous substances). This event occurs in the huge town greenhouse (a modified hockey rink) where all local communities in the Mackenzie Delta region of NWT have plots for growing a great variety of vegetables. Similar events occur in other larger northern communities.

Lady beetles are also part of the 'balance of nature'. Because they are frequently seen and easily identified, they can be helpful in monitoring the condition of the environment. Some kinds of lady beetles have become rare and have undergone rapid declines for reasons that are not entirely understood. Knowing more about lady beetles may be a step toward a better understanding of ecology in the north. Prior to this book there was nothing to help with the monitoring of this group of insects in NWT.

On the inside front cover of the book is written: "If you would like this information in another official language, call us". The nine official native languages used in NWT are listed. It is also available in French and the English version has a lot of French text. Flip to the inside back cover to find a list of helpful resources, including the complete Canadian context for this work and the major sources of information (the fit, the basis, and where to go further).

The first part of the book is full of valuable general information. It starts with a checklist of NWT lady beetles. This is followed by the characteristics and ecology of lady beetles. Morphological features are illustrated and can be conveniently found at the front of the book. These pages are used with the key and species descriptions and will be referred to often. This first part answers most of the questions people frequently ask. Did you know that the Transverse Lady Beetle (*Coccinella transversoguttata*), although not yet endangered, is con-

sidered to be a species of "Special Concern" by the Committee on the Status of Endangered Wildlife in Canada? This is because it has declined greatly in southern Canada, but in NWT large declines have not yet occurred. This is yet another indication of NWT having a less impacted environment than southern Canada (but note that effects of climate change may be more pronounced in NWT than in any other Canadian province or territory).

At the end of this general section is an unusual identification key to the species. This key is a series of alternative choices that lead to the identity of a species. What makes it unusual is that it is not technical and is based on features of easily evaluated colour patterns.

The species information, with a full page for each species, is half of the 75-page book. The layout of these pages is very well planned with an illustration of the insect colour and pattern in the upper left and a distribution map in the lower right. Information on various subjects is readily available under bold headings. Note that Yukon, northern British Columbia, and the northern prairie provinces border on NWT and this book will be useful in those regions and beyond.

Although it does not have an index, it is easy to make one. A checklist starting on page four is available for page numbers (on the left margin). I suggest that if you are going to be using the book a lot, just leaf through it and add the page numbers to this list. It is easily done because the species accounts are in the same order as the species in the checklist beginning with the Winter Lady Beetle (*Brumoides septentrionis*) on page 38. This is a pleasant way to develop some familiarity with the diversity of lady beetles.

What I like most about this Guide is that, like its companion guides listed below, it will inspire contact with nature and a better understanding of the Canadian north. These are a few of the things that we definitely need. It deserves an award!

See also:

Environment and Natural Resources. 2016. Butterflies of the Northwest Territories. Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada.

Environment and Natural Resources. 2017. A Field Guide to Bumble Bees of the Northwest Territories. Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada.

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Naiades et exuvies des libellules du Québec : clé de détermination des genres

By Raymond Hutchinson et Benoit Ménard. 2016. Entomofaune du Québec (EQ) Inc. 71 pages, 116 anatomical drawings, and 15 plates of illustrations (79 colour photos), 25.00 CAD, Cloth with spiral-binding and thick, semi-gloss paper for intensive use in the lab. Available from <http://entomofaune.qc.ca>.

This guide is most importantly a key to the determination of the genera (groups of similar species) of nymphs (naiads, larvae) of the dragonflies and damselflies of Quebec. As Michel Savard very correctly points out in the Foreword, an accurate name derived from a key is an essential starting point from which a huge amount of information on a species becomes available. This book was partly prepared to assist in the provincial survey aimed at developing an ongoing dragonfly atlas project in Quebec. It will be of value in all of eastern Canada and the adjacent United States where genera are similar.

The authors are in an excellent position to provide information on dragonfly larvae. Both have written many scientific and popular articles about dragonflies. Raymond Hutchinson has served for decades as the science teacher at the children's camp at Port-au-Saumon. Benoit Ménard is relentless in his hobby pursuit of dragonflies and uses his artistic talents to great advantage. All artwork in the book is his. Both authors have reared many hundreds of dragonfly larvae to adults in order to make a connection between features of larval skins and adults of many different species. They have popularized dragonflies with the public through popular articles, TV programs, radio and newspaper interviews, presentations, and workshops. In science and field biology they successfully promoted the study of dragonfly larvae which has led to new ecological understanding and discoveries of new species in Quebec. Author credibility varies among books, but this is as good as it gets.

On the back cover this book is advertised as a guide "for the Francophone naturalist". An informative book is one that anyone can benefit from regardless of language or how much effort has to be used to learn from it. This is simply an informative book that is in French because it is focussed on Quebec. I recommend it to the Anglophone naturalist as well because it is helpful for a region that is three times the size of Quebec to the south, east, and west. The essential part of the book, the key, is not difficult for anyone to understand. For example, it is easy to imagine that "première partie de l'antenne" means the "first part of the antenna". There are illustrations with arrows to help.

The book is valuable for many reasons. There is the issue of convenience. If you want to identify dragonfly larvae you will have to deal with the larger keys to genera in Needham *et al.* (2014) and Westfall and May (2006). This is because keys to larger geographic areas are longer and more complicated because of the increased number of taxa (many of which do not occur anywhere near the area of interest).

Then there is the question of why you might want to identify dragonfly larvae to genera at all. Well, dragonflies are useful bioindicators but at a particular time when you survey adults, not all dragonflies in the area will be flying because flight times for different species vary. Some will only be present as larvae while others will have already emerged for a secretive life in the forest canopy leaving only the empty exuviae (skins from larval transformation) as indicators of their presence. Only by surveying the larvae and the exuviae as well as the adults is a complete survey possible. This idea is emphasized by the authors and some evidence is available to support it (e.g., Catling 2003).

The introductory section is full of interesting information. Behaviour and ecology are well summarized. Some dragonflies are so secretive as adults that there is no other way to find them than to search for the nymphs and exuviae. Without understanding the larvae, you know only 10% of the dragonfly's life. This section also indicates how to distinguish dragonfly and damselfly larvae from other aquatic insects and from each other. It also describes how to catch the larvae (also called naiads or nymphs) using the preferred flat strainer net, which has revolutionized the collecting of aquatic insects (and was popularized by the authors). The first part of the book also contains a very helpful and informative overview of aquatic environments occupied by the different genera. There is information available for grouping Quebec dragonflies under habitats (e.g., Hutchinson and Ménard 2007a; Catling 2009; Hutchinson 2011) which may be outlined in an update.

The key is outstanding, based on the most easily used characters and with illustrations to assist in most of the decisions. Having identified a species to genus, it is necessary to return to the basic North American manuals which are referenced in the text (Westfall and May 2006; Needham *et al.* 2014), but by this time some of the most difficult work has been easily accomplished. If these latter North American manuals are not available, there are some other options for species identification. For example, Quebec (and northeastern North America) has many species in common with Michigan, so the online keys updated to 2017 in Bright and O'Brien (2017) will be helpful. See also Bright (2017) for *Ophiogomphus* nymphs. These keys sometimes employ different (and perhaps better) characters than the older keys in the larger manuals (and they are shorter).

Following the key are 12 plates of outstanding illustrations. The value of these in identification is substantial, whether careful line drawings or photographs of excellent quality. These pages contain 95 pictures and of course there are numerous illustrations elsewhere.

It is a very well illustrated book. The plates are followed by a useful glossary, list of major references, and a helpful index.

A companion update or a second edition for this book seems to be a good idea for three reasons:

(1) Although some groups (genera) are difficult and require more work, there are distinctive species in some of these genera that are easily identified. For example, the discovery of Maine Snaketail (*Ophiogomphus mainensis*) in Ontario was based on larvae which have the most distinctive antennae in the genus (Catling and Brownell 1999). Also, the discovery of l'épithèque de Brunelle (*Neurocordulia michaeli*) in Quebec was based on exuviae with a key to the latter in the Charest and Savard (2014) report.

(2) The members of some genera are easily identified and keys with illustrations have been produced for all that occur in eastern Canada. This is true for *Stylurus* (e.g., Catling 2000; Bright and O'Brien 2017).

(3) Along the same lines there is information on the ecology and characteristics of larvae, some especially referring to Quebec (and eastern Canada) that could have been mentioned here (perhaps in the list of genera and associated habitats). See, for example, Catling (2004) and Hutchinson and Ménard (2007b).

Making reference to this information, or better still, including it, would be helpful to the dragonfly survey effort. It seems unfortunate not to make some useful information available only because it cannot be complete for some groups.

This work will further promote the study of dragonfly larvae, something that the authors have been doing for a long time. It is excellent and valuable, and yet another important contribution from two outstanding Canadian field biologists.

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A Field Guide to Insects of the Pacific Northwest

By Robert Cannings. 2018. Harbour Publishing. 7.95 CAD, Pamphlet.

This field guide is a handy little pamphlet that interested naturalists can easily bring anywhere with them to help identify common insects around the Pacific Northwest. The field guide starts with a small amount of information about what an insect is, how insects grow, and why insects are important. It has attractive macro photos of 55 species (although the publisher's website [Harbour Publishing 2018] says there are more than 60) organized in 19 taxonomic orders. A very short description of the species (or sometimes, of the order) next to each image provides a bit of background about the species. Its glossy, laminated finish would stand up to some light precipitation, but would not last in any significant rain. This field guide is clearly targeted towards amateur naturalists interested in learning some of the basics about insect ecology and identification in the Pacific Northwest and, from that perspective, it is excellent.

The author, Dr. Robert Cannings, is Curator Emeritus of Entomology at the Royal British Columbia Museum, where he has been studying insects since 1980. His main interests are in dragonflies and robber flies; he wrote the handbook to dragonflies of British Columbia (Cannings and Stuart 1977).

Given its target audience, this is not an exhaustive field guide. It lists between one and nine species for each taxonomic order; five taxonomic orders with rare or hard to see species were not included. According to the publisher's website, the species that were chosen are common but not familiar, the goal being to introduce amateur naturalists to the diversity of insects within the region. From this perspective, the author did an excel-

lent job choosing insects, focussing on interesting native species that an amateur naturalist is likely to come across if they were actively looking for insects. For example, within the Order Hymenoptera (Sawflies, Wasps, Bees, and Ants), the guide lists the Western Bumble Bee (*Bombus occidentalis*) and Blue Orchard Bee (*Osmia lignaria*), but not the Western Honey Bee (*Apis mellifera*), even though most members of the public would think of a honey bee when they think about bees. The guide focusses on the wonderful native bees of the region rather than listing the well known, yet introduced, Western Honey Bee.

While this guide is an excellent introduction to the diversity of insects in the Pacific Northwest, it does not contain the information that is typically expected from a field guide. Nonetheless, it is a good resource for amateur naturalists interested in learning about the insects in this region.

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ZOOLOGY

A Natural History Study of Leech (Annelida: Clitellata: Hirudinida) Distributions in Western North America North of Mexico

By Peter Hovingh. 2016. Alphagraphics. 460 pages, freely available, print or electronic (DVD). "This is a free and public available document for the benefit of naturalists, scientists, those who manage natural resources, and the curious." For a copy, contact Alphagraphics, 9247 South State Street, Sandy, Utah, USA, 84070.

Specifically for Canadian field biologists, this work will serve as a standard and current reference for freshwater leech occurrence over a large area of western Canada. Recent works for other parts of Canada include Madill (1988), Ricciardi (1991), Grantham and Hann (1994), Schalk *et al.* (2001), Madill and Hovingh (2007), and Langer *et al.* (2018).

In general, this is also a major contribution to the distribution and taxonomy of leeches. It began with the purpose of determining the geographical distribution of freshwater leeches and possible aquatic connectives explaining this distribution. It was initially aimed at the question of which leech fauna occurred in isolated springs of the eastern Great Basin and how and when the leeches got there. These and related questions are discussed in detailed sections on high elevation, the Pacific Coast, Columbia-Snake River drainages, the Great Basin, the Colorado River Basin, and the Western Great Plains.

The basic tools of analysis are geography, fish distributions, and drainage basins. It will be of interest to Canadians that the collections from field surveys supporting the work in Canada and Alaska are at the Canadian Museum of Nature, Ottawa (CMN-A). There are eight main sections. Those of most interest to Canada are the first and third sections: 1. Species descriptions and distributions; and 3. Latitudinal postglacial movement. Each section has a table of contents, abstract, introduction, methods, contents, and a comprehensive and very useful list of references.

"Species descriptions and distributions" includes distribution maps for 48 species followed by notes on 38 species accounting for distribution, taxonomy, and distinctive features. Distributions are thought to have developed in the Cretaceous period with differentiation of genera in the Paleocene epoch. The maps and information are current, but illustrations of the leeches are also useful in recognition. These illustrations are derived from one of the classic identification tools of Klemm (1982), which is available by online request (see Literature Cited, below). The text on individual species provides specific information on distributions. The distribution of the Fish Leech (*Piscicola geometra*), for example, is noted as congruent with that of a major host, Northern Pike (*Esox lucius*), and collection data for Canadian collections is in the appendix on page 187.

The taxonomic details are helpful. It is noted, for example, that previous ecological and distributional studies of *Theromyzon rude*, previously the North

American bird leech, cannot assume the correct name unless reproductive organs were examined and described. This means that the very high levels of parasitism of waterfowl reported north of Yellowknife by Bartonek and Trauger (1975) may have involved another species, despite the fact that these authors were careful with identification at the time (see discussion of identification in Trauger and Bartonek 1977). The high levels of parasitism by *Theromyzon* and the fact that more species of waterfowl had been reported as parasitized by leeches in the Northwest Territories than anywhere else in North America (Trauger and Bartonek 1977 published a map) is still of interest, but the need for correct names in retrieving scientific information makes it important to track the changes and redefined species. For *Theromyzon* it will be helpful to consult the work of Oosthuizen and Davies (1992, 1993) and Davies and Oosthuizen (1993). The latter includes a helpful chart for the identification of all North American species.

In "Latitudinal postglacial movement" it is suggested that five leech species may have occurred in unglaciated Beringia, and four species may have occupied glacial refugia on the west coast from Haida Gwaii northward. Postglacial colonization followed dispersal patterns similar to those of fish. Spread from postglacial refugia in eastern Canada has been discussed elsewhere (Madill and Hovingh 2007). An interesting story is associated with the leech *Cystobranchus mammillatus*, which is hosted by the Eurasian Burbot (*Lota lota lota*). This fish subspecies occurs east to the Mackenzie Delta but the North American Burbot (*Lota lota maculosa*) occurs north to Great Slave Lake. Very little mixing has been reported in the Mackenzie River Basin. It seems possible that the North American subspecies reached the basin from the unglaciated territory to the south (Missouri-Mississippian), whereas the mainly Eurasian subspecies occupies its unglaciated Beringian territory. In North America, the leech has thus far been reported only from the Mackenzie Delta. Could it be a true disjunct (from western Siberia) surviving in the relatively mild delta region, and lost from the intervening territory as a result of Pleistocene climatic extinctions? To the remarkable fauna of the Northwest Territories, we can add (at least for now) a fish leech that is found nowhere else in North America.

This work is full of interesting material. As well as being a very helpful source on the natural history and taxonomy of leeches, there is detailed coverage of geological and climatic history and the distribution and

taxonomy is updated over the classic work of Klemm (1985) and others. Much of what has been written about North American leeches is referenced here making the work a useful foundation for a better understanding of a fascinating group.

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OTHER

The Inner Life of Animals: Love, Grief and Compassion – Surprising Observations of a Hidden World

By Peter Wohlleben. Translated from the German by Jane Billingshurst. 2017. Greystone Books. 277 pages, 24.95 CAD, Cloth.

The book has not one but two subtitles: “Love, Grief and Compassion – Surprising Observations of a Hidden World”. In general, subtitles give me negative feelings, but as everything has them nowadays I have given up caring. Of the three versions of the title, I think the third is the least appropriate. For most naturalists there is not a lot here that is likely to surprise them. The book is a collection of anecdotes and observations, some commonplace, some very astute, about animal behaviour. They derive in part from the author’s own observations on a farm and woodlot in Germany and in part from an eclectic selection of readings in the press, on the web, and—to a lesser extent—in the popular and peer-reviewed scientific literature. Only 23 of 101 references are to original scientific papers. A foreword by Jeffrey Moussaieff Masson gets big billing on the cover but consists of only four pages.

The author begins with a few tart comments on the sins of ‘scientists’. He is seconded in these opinions by the aforementioned Masson. Like many other writers, they want us to believe that science is obscuring the truth about animal intelligence, not through malice, but through blind adherence to antiquated ‘science-think’. This is certainly a widespread belief and one that contributes to the general distaste for ‘expert’ opinion. It is unfortunate, because I think many of the author’s criticisms are aimed at straw wo/man thinking characteristic of the 20th, rather than the 21st century. His avowed intent is to “help you see the animal world... not as mindless automatons driven by an inflexible genetic code [apparently his idea of science-think], but as stalwart souls and lovable rascals”. Does he succeed?

Overall, if anyone did believe in the ‘mindless automatons’ interpretation of animal behaviour, then I think this book will certainly help to disabuse them: spending any substantial amount of time observing animals in the wild or even pets in our homes will do the same. Ani-

mals undoubtedly have the capacity to love and hate, to cheat and act remorseful, to show fear, bravery and indecision, to be selfish and selfless and everything in between. If you are looking for examples of such behaviours, then this book is a good place to start. I certainly gleaned many tidbits of Natural History that I was not aware of.

Among the different animals covered, bees, chickens, goats, dogs, and horses get plenty of coverage, as they belong to the author’s household. He gives a good shout-out for pigs, which I was glad to see because I always feel they don’t get their dues as truly intelligent and sensitive animals, a fact that forced me to renounce bacon in later life. The author also writes a good deal about ravens and crows, which he posits as “the apes among birds”. I particularly liked his description of a crow being evasive about caching an acorn while being watched. I have had an identical experience trying to watch ravens caching seabird eggs: they won’t do it as long as anyone else, human or raven, is watching.

Sy Montgomery, author of *The Soul of an Octopus* (Atria Books 2015), says on Amazon that *The Inner Life of Animals* “will rock your world”. If you are an experienced naturalist, that is unlikely to be true, but if you know someone who likes kitten videos on YouTube (and there are millions of them, both viewers and videos), but does not know a lot about animals otherwise, then this book might make the perfect gift. The book was published in collaboration with the David Suzuki Institute and supported by the Canadian and British Columbian governments, as well as, more obscurely, by the Canada Council and British Columbia Arts Council, and printed in Canada on ancient-forest-friendly paper.

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The Subjugation of Canadian Wildlife: Failures of Principle and Policy

Max Foran. 2018. McGill-Queen's University Press. 439 pages, 39.95 CAD, Cloth.

THIS IS A VERY IMPORTANT BOOK. The title of the book very aptly sums up its contents. It is not a balanced account of wildlife management in Canada but a polemic about its failures. As such, it is an uncomfortable read for (full-disclosure) an ex-employee of Environment Canada. I began by being very resistant to the central message of the book: that our failure to protect Canadian wildlife stems from a "homocentric" approach to nature, but by the end I was, if not converted, at least much more respectful of the author's arguments. Moreover, his contentions are extensively documented in 120 pages of small-type notes and bibliography, so these are well-founded arguments.

The book is in two sections: Part 1 deals with our "belief system" relating to nature and how it manifests itself in the treatment of predators, especially apex predators (wolves, grizzlies, and Cougars [*Puma concolor*]), as well as 'other wildlife' exemplified by the contentious spring hunt for Black Bears (*Ursus americanus*), Ontario's Mourning Dove (*Zenaida macroura*) hunt, and the notorious Newfoundland seal hunt. Part 2 deals with wildlife habitats and how we manage them, including a very useful discussion of the various legislative tools available to the Government of Canada, the provinces, and the territories and how they are being applied (or misapplied). This section deals at length with the *Species at Risk Act* (SARA), where Environment Canada is the villain of the piece, as well as with the establishment and management of protected areas, in which Parks Canada is featured as a major sinner. Among the good guys exposing the sins of the bureaucracy, Ecojustice and the Canadian Parks and Wilderness Society feature prominently.

Two themes run through the book: the first is the idea that animals, at least higher vertebrates, have a capacity for suffering that should require more humane treatment by us than is currently the norm. This theme echoes, in a more formal and scholarly manner, the concerns of Wohlleben's book covered in the previous review (Canadian Field Naturalist 132: 76, <https://doi.org/10.22621/cfn.v132v1i1.2127>). In fact, the two books make an interesting contrast in styles, with Wohlleben trying to convince us gently and humorously to be nicer to animals, while Foran hits us on the head with a two-by-four.

The second theme is the over-riding influence of economics, in the form of human security, jobs, and profit, in determining the outcomes of human-wildlife conflicts. This is hardly news, but the very detailed descrip-

tions of events surrounding the cases of the Black-tailed Prairie Dog (*Cynomys ludovicianus*), the Greater Sagegrouse (*Centrocercus urophasianus*), the Nooksack Dace (*Rhinichthys cataractae* – Chehalis lineage), the Southern Resident Killer Whales (*Orcinus orca*), and others, highlight the sort of wilful blindness that goes into attempts to satisfy both economic and environmental interests. These sections would be very valuable reading for any politicians or public servants engaged in implementing SARA. They illustrate the fact that, in a society where information is readily available, decisions are open to the judgement of history.

I did have some caveats about the book. In a work that deals, among other things, with the ethics of hunting, the word 'meat' never appears. Nor was our relationship with pets or domestic animals discussed. But the belief system that the author laments, in which animals are treated as disposable resources, surely stems from our carnivorous habits. The heavy hunting of Moose (*Alces americanus*) in Newfoundland, for instance, treated as inhumane culling in the book, provides a very important element in the local diet. The same goes for deer hunting in Haida Gwaii and doubtless in many other places, even ignoring the obvious needs of indigenous peoples, especially the Inuit. Culling—the killing of animals to adjust ecosystem imbalances—comes in for much criticism, but the many cases where unique local ecosystems are being very clearly degraded by introduced species (e.g., rats or Raccoons [*Procyon lotor*] on seabird colonies, deer on Anticosti Island) are not considered. In fact, the author casts doubt on the validity of any sort of cull carried out with a view to rebalancing the ecosystem, claiming we do not have sufficient knowledge of ecosystem dynamics.

For me, among the most distressing shortcomings of our attempts to conserve wildlife in Canada is the fact that, despite the vast size of the country, many of our protected areas are too small to support viable populations of large mammals. You have to ask yourself whether, if a large country like Canada, with a well-educated population, generally inclined to look favourably on wildlife, cannot manage its wild species sustainably, what hope is there for the planet as a whole? The wake-up calls have been so loud, for so long, that our brains no longer hear them. Perhaps that is why Max Foran felt he had to adopt such a strident tone in this book. It is a very sobering read.

TONY GASTON

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Half-Earth: Our Planet's Fight for Life

By Edward O. Wilson. 2017. Liveright Publishing Corporation. 272 pages, 25.95 USD, Cloth, 16.95 USD, Paper.

In *Half-Earth*, renowned entomologist and conservation biologist Edward O. Wilson argues for why we should protect half of Earth's surface in order to conserve biodiversity. Earth's biodiversity is disappearing at the fastest rate in history, and this high extinction risk is linked directly to human activities, including habitat loss and overexploitation. And because we have yet to describe all species on Earth, it is likely that a large number of species will go extinct before we have the chance to describe them. E.O. Wilson has led a career filled with discovering species new to science, so he is well suited to describe and champion the race to describe life on this planet before it disappears. But the goal isn't simply to have the opportunity to describe species and learn more about the natural world around us. The goal is to preserve biodiversity because it is the ethical thing to do, species extinction has cascading effects within ecosystems which are difficult to predict, and because biodiversity benefits humans in countless ways.

In this book, Wilson first describes the conservation challenge (i.e., species are going extinct more quickly than we can discover them). He then describes the diversity of life that we do know, showing examples from a wide range of taxa. Finally, he makes a case for why we need to preserve half of Earth's surface, and makes recommendations for key areas that we should preserve. Unlike other recommendations (e.g., Aichi Biodiversity Targets, <https://www.cbd.int/sp>) for how much area needs to be preserved, Wilson uses the ecological concept known as the species-area relationship to back-up his recommendation. According to the species-area relationship, if half of Earth's habitats are preserved, then 85% of Earth's current biodiversity will not go extinct, at least not from the loss of habitat or overexploitation within that habitat. This does not account for other threats, such as climate change, but rather focusses on habitat loss, which is the greatest threat to biodiversity. Wilson does allude to these other threats in this book, but they are not the main focus of the Half Earth argument. It is fitting that Wilson uses the species-area relationship to back-up his thesis, because he is well known for using the species-area relationship in his seminal work with Robert MacArthur, the theory of island biogeography. The species-area

relationship has been shown countless times in nature, so its utility for the Half Earth argument seems sound.

My main critique of this book is that it mostly focusses on terrestrial biodiversity. Wilson is a terrestrial ecologist, so he likely focussed on the aspect of biodiversity with which he was most familiar. It could even be argued that in a popular science book such as this, it is probably better to use examples from areas that the readers are most familiar with (i.e., on land, rather than in water). However, it is likely that the greatest number of undiscovered species live in marine environments. Wilson does give a few marine examples, especially in Chapter 13, "The Wholly Different Aqueous World", where he focusses on the marine world and provides examples such as the number of invertebrate species that can be found just within the surf along a beach. However, in Chapter 15, "The Best Places in the Biosphere", all the examples are focussed on the terrestrial biosphere. I believe that this book would have benefited from a more balanced perspective on biodiversity, such that the preservation of half Earth doesn't just come across as preservation of half of terrestrial Earth, with almost no mention of aquatic Earth. Wilson could have spent more time focussing on how to achieve conserving half of Earth. Indeed, a quick web search reveals counter opinions that half of Earth is too much to conserve. As well, Wilson could have led readers through the process of achieving half Earth. Current conservation targets, such as the Aichi targets, aim for 17% of terrestrial area and 10% of marine areas to be protected by 2020. Many countries are struggling to meet these targets, let alone protecting 50% of the planet. Wilson does provide some guidance on which areas should be preserved, specifically aiming at biodiversity hotspots and areas with unique biodiversity, as well as promoting corridors connecting such areas. These are useful suggestions, but are not that different from suggestions for the Aichi targets.

This book will be an excellent read for anyone who wants to understand the current conservation crisis, learn more about biodiversity, or simply read a well-written book about the natural world.

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Best Places to Bird in the Prairies

By John Acorn, Alan Smith, and Nicola Koper. 2018. Greystone Books. 266 pages, 24.95 CAD, Paper.

I was looking forward to reviewing this book because I am not that familiar with birding sites in Saskatchewan and Manitoba; however, I also learned of a few new sites in Alberta, such as Gull Lake and the Alberta Grain Terminal in Edmonton (think Prairie Falcons [*Falco mexicanus*] and Gyrfalcons [*Falco rusticolus*] attacking all of those Rock Pigeons [*Columba livia*] feeding on spilled grain). This is the second “Best Places to Bird ...” book (see my review of the Cannings’ book on British Columbia in *Canadian Field-Naturalist* 131: 85, <https://doi.org/10.22621/cfn.v131i1.1974>) by Greystone Books—perhaps a series is in the offing?

Of course, any ‘best of’ book will leave out some of the reader’s favourite places. One such place for me is Waterton Lakes National Park, where one can bird from prairie grasslands to the alpine in a single day. However, I cannot quibble with any of John Acorn’s choices as great places to go birding. The Alberta chapter does not seem to have any geographical order to the sequence of sites, so it is harder for birders to read up on good areas in proximity to where they are. The Manitoba section is also quite random, while the Saskatchewan section handles this much better. There is a two-page map spread of the three provinces immediately after the table of contents, with the sites named and numbered. The relevant map is then repeated in advance of the descriptive section for each province.

Each chapter covers a site and begins with a general description of why it’s special, often with personal anecdotes from the author. This is accompanied by at least one excellent photo of a species described therein. That is followed by a more detailed “Birding Guide” that describes what species you might expect to find, where, and in what season. The “Getting There” section is often longer than the “Birding Guide”, with lots of detail, which is helpful because many of these areas will

not be found on provincial road maps (and I suspect your vehicle’s navigation system might not be much help in some areas either). There is an excellent detailed map for each site which uses “terrain” view, showing streets and roads, rather than just a sketch map. There is some repetition between these two sections, but I’m not sure it could have been handled any differently.

I noticed a few typos and other errors: the photo of a Harlequin Duck (*Histrionicus histrionicus*, p. 128) is captioned as an adult male but is actually a subadult male, which is also the typical age class to be found east of the breeding range. Right and left forks of the road were mixed up in the road description on page 139. And Archie Belaney was known as Grey Owl, and may have been great, but was not known as Great Gray Owl (p. 161; probably a result of relying on the computer’s spell checking function). The map of Beaudry Provincial Park (p. 208) does not label the “prairie trails” which are referenced in the description and which could be helpful. There is occasional inconsistent use of plurals of bird names throughout the book; for example, a sentence that references Canvasbacks (*Aythya valisineria*) in the plural and Ruddy Duck (*Oxyura jamaicensis*) in the singular (p. 241). An additional resources chapter, with websites, birding hotlines, agency/site phone numbers, etc. might have been helpful.

With the exception of Churchill, Manitoba, the book really only covers the southern third of the Prairie Provinces...but then that is where most of the access is, and the most habitat diversity. And that is where most of the human population lives and visits. If you are planning to visit any of these three provinces, or even if you live there but want to explore new areas, this guide will definitely help you to maximize your birding experience.

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Deep Into Yellowstone: A Year's Immersion in Grandeur and Controversy

By Rick Lamplugh. 2017. CreateSpace Independent Publishing Platform. 294 pages, 15.95 USD, Paper.

Deep Into Yellowstone is a fascinating read about Rick Lamplugh's year-round experience of living at the gateway of Yellowstone National Park. After having volunteered in the Lamar Valley for three consecutive winters at the historic Lamar Buffalo Ranch from 2012 to 2014, and writing his first tome *In the Temple of Wolves* (self-published 2013) about that experience, Rick and his wife Mary decided to move. They moved from Oregon—their home of 35 years—to Gardiner, Montana, to be close to and permanently part of the grandeur of the world's first national park. They were insulated from the world's ills when volunteering deep within the park in the Lamar, but quickly found themselves living at the edge of controversy in Gardiner. Here there was the hunting of Yellowstone wolves outside the park, the debate about the economic and ecosystem benefits of wolves, the community effort to stop a possible gold mine on the park's border, the outrage over the plan to remove grizzlies from the endangered species list, and the battle to stop the slaughter of park bison (p. 19).

Having visited Yellowstone over 20 times and written my own book, *My Yellowstone Experience* (Eastern Coyote Research 2013), on the great park, I was engrossed with Lamplugh's easy-to-read writing style and engaging accounts. He immerses us in all four Yellowstone seasons, starting with winter, writing 7–9 essays during each season (31 total). There we get to go on “hikes” and cross-country skiing forays with Rick and Mary (and usually another friend or two) and learn about the special resources of the park including the park's many thermal features and its abundant and diverse fauna. We learn about the importance of predators to the ecosystem—especially wolves—and the controversy about the degree to which wolves are benefiting the ecosystem. I tend to agree with his conclusions—and that of Bob Beschta of Oregon State University (Chapter 23)—that wolves have dramatically benefited the ecosystem and have been the key to returning the park to ecological health. Lamplugh also shares incredible insights of raven-wolf behaviour and how the two have evolved together making some wonder how ravens survived before wolves returned to the ecosystem in the mid-1990s. As Lamplugh states, “The presence of wolves and grizzlies defines wildness and causes me to use my senses fully; to be in the moment, and to accept my humble place in nature's grand scheme” (p. 261).

I particularly appreciated how Lamplugh wears his heart on his sleeve and fights for the animals and resources that cannot speak for themselves. He is clearly not a fan of how the states of Montana, Idaho, and Wyoming plan to hunt Grizzly Bears (*Ursus arctos*) after delisting (pp. 80–81) similar to how those jurisdictions have allowed a veritable slaughter of wolves outside the park since the states retained control of man-

aging those animals (pp. 14–15). Rick also relates to us about the tragic and angering circumstances of park bison getting captured and sent to slaughter by Yellowstone wildlife managers (a large bison trap near Gardiner is located within the park) and killed by a “firing squad” (Chapter 3) of hunters at the park's immediate border all for leaving the invisible protections of the park. Some 7000+ Bison have died at Yellowstone's borders since 1985 (p. 57). It is particularly personal for him when he is biking and skiing in areas where bison will die later on that winter. These in-depth descriptions of his experiences will inspire readers to help protect the wildlife and landscape of this treasured national park.

Rick coins the term “meanderthal”, one who likes to explore/wonder, and it perfectly describes his approach to life. While on a hike or a backpacking trip, if he sees an animal track—say a fresh wolf print in a dusting of snow—he will follow the animal and see how it was behaving in its environment. Maybe he—or more aptly Mary with her keener eye—will spot the actual animal. While we are deep within the husband and wife team's adventures, Lamplugh often digresses and explains complex science in layman's terms ranging from animal behaviour such as the ecological benefits of wolves or wolf territoriality and aggression to the unique hydrothermal features and geology of the region such as how geysers function (p. 135). His detailed descriptions provided me with a reminder of the “soothing sulfur-scented breezes” (p. 132), that “timeless Yellowstone scent” (p. 123), surrounding geyser basins and other geothermal areas, as well as the slick, scented oil smell of sagebrush when rubbing its tiny grey-green leaves (p. 155). Yet there is just enough science quoted from professionals to provide the reader an accurate understanding of each issue with “eyes wide open” (Chapter 21) but not too much where one might get bored, or confused, by reading highly technical information.

Along the way, Rick takes us into the halls—literally—of local buildings where he attends meetings to help protect wolves and other creatures. While the vast majority of people support conserving animals like wolves, most don't know that a small minority is gunning for wolves as the animals leave the protection of the park's seamless borders. Fortunately, wildlife managers are learning the values of conserving wolves and have—up until now—kept hunting quotas relatively low so wolves don't get killed when leaving the park. Having people like Rick and Mary there to defend them is vital.

The end of the book focusses on folks loving our national parks to death. Currently, over four million people visit Yellowstone a year even though it's only really built to support around 2.5 million. This puts a strain on the park's incredible resources, and Rick pro-

poses solutions that benefit the park, such as having daily quotas and a reservation system so the park isn't loved to death. He correctly points out that certainly not all people, and especially not all politicians, would support these restrictions. He even notes that he is part of the problem whereby watching wildlife and habituating them to people—such as the Grizzly Bear he describes (p. 254)—can make it a target if that individual leaves the park and meets a person having a rifle, not binocular, in his eye-sights.

I really enjoyed the book and Lamplugh's writing style. In the acknowledgments he describes that he self-published the book yet there were only a few very minor errors, as it has been professionally edited. There are no pictures throughout the book except on the covers and there is no introduction to set the stage; there-

fore the book—after the table of contents—just starts in winter. However, the book is so easy-to-read that is not a distraction. There is also no index, although one is not really needed for an essay-styled book, nor is there a list of references used at the end of the book despite him clearly using many sources within the book. This last omission does not sidetrack from the value of the read because he quotes most sources by name or sometimes by book or article written. So, if you want to travel to, inquire about, or safeguard the world's first national park, I highly recommend this book. *Deep into Yellowstone* will give you a deep appreciation for Yellowstone and a better knowledge of the controversies threatening the park and its surroundings.

JONATHAN (JON) WAY

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NEW TITLES

Prepared by Barry Cottam

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BOTANY

Atlas of Poetic Botany. By Francis Hallé. Contribution by Éliane Patriarca. Translated by Erik Butler. 2018. MIT Press. 128 pages and 42 colour illustrations, 24.95 USD, Cloth.

Flora of the Pacific Northwest, Second Edition. An Illustrated Manual. By C. Leo Hitchcock and Arthur Cronquist. 2018. University of Washington Press. 936 pages, 86.00 USD, Cloth.

***Flora of Florida, Volume VI: Dicotyledons, Convolvulaceae through Paulowniaceae.** By Richard P. Wunderlin, Bruce F. Hansen, and Alan R. Franck. 2018. University Press of Florida. 352 pages, 70.00 USD, Cloth.

Brilliant Green: The Surprising History and Science of Plant Intelligence. By Stefano Mancuso and Alessandra Viola. 2018. Island Press. 192 pages, 17.00 USD, Paper. Cloth and E-book editions published in 2015.

The Biology of Grasslands. Biology of Habitats Series. By Brian J. Wilsey. 2018. Oxford University Press. 320 pages, 95.00 CAD, Cloth, 45.95 CAD, Paper. Also available as an E-book.

Brilliant Green: The Surprising History and Science of Plant Intelligence. By Stefano Mancuso and Alessandra Viola. Foreword by Michael Pollan. 2018. Island Press. 192 pages, 18.95 CAD, Paper.

***Sedges and Rushes of Minnesota: The Complete Guide to Species Identification.** By Welby R. Smith. Photography by Richard Haug. 2018. University of Minnesota Press. 696 pages, 1100 colour plates, and 248 maps, 39.95 USD, Paper.

CONSERVATION

Where the Animals Go: Tracking Wildlife with Technology in 50 Maps and Graphics. By James Cheshire and Oliver Uberti. 2017. W.W. Norton. 192 pages, 39.95 USD, Cloth.

Essential Readings in Wildlife Management and Conservation. Edited by Paul R. Krausman and Bruce D. Leopold. 2018. Johns Hopkins University Press. 696 pages, 53.00 USD, Cloth, 49.95 USD, Paper.

Ecology and Recovery of Eastern Old-Growth Forests. By Andrew M. Barton and William S. Keeton. 2018. Island Press. 288 pages, 80.00 USD, Cloth, 40.00 USD, Paper or E-book.

Species Conservation: Lessons from Islands. Ecology, Biodiversity and Conservation Series. Edited by Jamieson A. Copsey, Simon A. Black, Jim J. Groombridge, and Carl G. Jones. 2018. Cambridge University Press. 396 pages, 131.95 CAD, Cloth, 51.95 CAD, Paper.

ENTOMOLOGY

***Beetles: The Natural History and Diversity of Coleoptera.** By Stephen A. Marshall. 2018. Firefly Books. 784 pages, 95.00 CAD, Cloth.

Aleocharine Rove Beetles of Eastern Canada (Coleoptera Staphylinidae Aleocharinae): A Glimpse of Megadiversity. By J. Klimaszewski, R.P. Webster, D.W. Langor, A. Brunke, A. Davies, C. Bourdon, M. Labrecque, A.F. Newton, J.-A. Dorval, and J.H. Frank. 2018. Springer. 891 pages, 249.99 USD, Cloth, 189.00 USD, E-book.

The Asian Hornet (*Vespa velutina*): Threats, Biology and Expansion. By S. Martin. 2017. IBRA. 106 pages, 32.50 GBP, Paper.

Insect Behavior: From Mechanisms to Ecological and Evolutionary Consequences. Edited by Alex Cordoba-Aguilar, Daniel Gonzalez-Tokman, and Isaac Gonzalez-Santoyo. 2018. Oxford University Press. 416 pages, 100.00 CAD, Cloth, 49.95 CAD, Paper. Also available as an E-book.

Insect Biodiversity: Science and Society, Second Edition, Volume 1. Edited by Robert G. Foottit and

Peter H. Adler. 2017. Wiley-Blackwell. 904 pages, 158.47 CAD, Cloth, 126.99 CAD, E-book.

Insect Biodiversity: Science and Society, Second Edition, Volume 2. Edited by Robert G. Foottit and Peter H. Adler. 2018. Wiley-Blackwell. 1024 pages, 180.00 CAD, Cloth, 144.99 CAD, E-book.

Pacific Northwest Insects. By Merrill A. Peterson. 2018. Seattle Audubon. 528 pages and 1725 colour photographs, 37.95 CAD, Paper.

Buzz: The Nature and Necessity of Bees. By Thor Hanson. 2018. Basic Books. 304 pages, 35.50 CAD, Cloth, 288 pages, 21.99 CAD, E-book.

Stouts, Millers & Forky-Tails: Insects of Newfoundland and Labrador. By Tom Chapman, Carolyn Parson, Hugh Whitney, and Peggy Dixon. 2018. Boulder Publications. 200 pages, 29.95 USD, Paper.

Butterflies of the World. By Adrian Hoskins. 2018. Johns Hopkins University Press. 312 pages and 368 colour photographs, 34.95 USD, Cloth.

Amazing Arachnids. By Jillian Cowles. 2018. Princeton University Press. 328 pages, 45.00 USD, Cloth, 35.00 USD, E-book.

ORNITHOLOGY

***Birds of Nunavut, Volume 1: Nonpasserines, Volume 2: Passerines.** Edited by James M. Richards and Anthony J. Gaston. 2018. University of British Columbia Press. 820 pages, 805 colour photos, and 155 maps, 125.00 CAD, Cloth.

***North American Ducks, Geese & Swans: Identification Guide.** By Frank S. Todd. 2018. Hancock House. 208 pages, 29.95 CAD, Paper.

The Cooper's Hawk: Breeding Ecology & Natural History of a Winged Huntsman. By Robert N. Rosenfield. 2018. Hancock House. 164 pages, 29.95 CAD, Paper.

Behavior of the Golden Eagle: An Illustrated Ethogram. By David Ellis and N. John Schmitt. 2018. Hancock House. 102 pages and 88 illustrations, 29.95 CAD, Cloth or Paper.

Papa Goose: One Year, Seven Goslings, and the Flight of My Life. By Michael Quetting. Foreword by Stacey O'Brien. 2018. Greystone Books. 248 pages, 29.95 CAD, Cloth.

The Handbook of Bird Families. By Jonathan Elphick. 2018. Firefly Books. 344 pages, 35.00 CAD, Paper.

Hummingbirds. By Ronald Orenstein. Photography by Michael and Patricia Fogden. 2018. Firefly Books. 256 pages, 35.00 CAD, Paper. Cloth edition published in 2014.

Far from Land: The Mysterious Lives of Seabirds. By Michael Brooke. Illustrations by Bruce Pearson. 2018. Princeton University Press. 264 pages, 29.95 USD, Cloth, 24.00 USD, E-book.

Owls of the World. By James Duncan. 2018. Johns Hopkins University Press. 192 pages and 127 colour illustrations, 29.95 USD, Cloth.

Listening to a Continent Sing: Birdsong by Bicycle from the Atlantic to the Pacific. By Donald Kroodsma. 2018. Princeton University Press. 336 pages, 21.95 USD, Paper, 16.99 USD, E-book. Cloth edition published in 2016.

ZOOLOGY

***Guide to the Parasites of Fishes of Canada. Part V: Nematoda.** By Hisao P. Arai and John W. Smith. Edited by Michael D.B. Burt and Donald F. McAlpine. 2016. Zootaxa 4185, Magnolia Press. 274 pages, free PDF available at <https://biotaxa.org/Zootaxa/article/view/zootaxa.4185.1.1>.

The Behavior and Ecology of Pacific Salmon and Trout, Second Edition. By Thomas P. Quinn. 2018. University of British Columbia Press. 548 pages, 70.00 CAD, Paper.

Vaquita: Science, Politics, and Crime in the Sea of Cortez. By Brooke Bessesen. 2018. Island Press. 256 pages, 33.95 CAD, Cloth.

Ecology and Conservation of the Diamond-backed Terrapin. Edited by Willem M. Roosenburg and Victor S. Kennedy. 2018. Johns Hopkins University Press. 296 pages, 79.95 USD, Cloth.

The Book of Snakes: A Life-Size Guide to Six Hundred Species from around the World. By Mark O'Shea. 2018. University of Chicago Press. 858 pages and 2400 colour plates, 55.00 USD, Cloth. Also available as an E-book.

Handbook of the Mammals of the World, Volume 8. Insectivores, Sloths and Colugos. Edited by Don E. Wilson and Russell A. Mittermeier. Illustrations by Toni Llobet. 2018. Lynx Edicions in association with

Conservation International and IUCN. 710 pages, 160.00 EUR / GBP, Cloth.

Walker's Mammals of the World: Monotremes, Marsupials, Afrotherians, Xenarthrans, and Sundatherians. By Ronald M. Nowak. 2018. Johns Hopkins University Press. 784 pages and 508 colour photos, 99.97 USD, Cloth.

Beachcomber's Guide to Seashore Life in the Pacific Northwest, Third Edition. By J. Duane. 2018. Harbour Publishing. 240 pages and 400 colour photos, 26.95 CAD, Paper.

OTHER

Island at the Centre of the World: The Geological Heritage of Prince Edward Island. By John Calder. 2018. Acorn Press. 280 pages, 24.95 CAD, Paper or E-book.

Kings of the Yukon: An Alaskan River Journey. By Adam Weymouth. 2018. Penguin UK. 288 pages, 16.99 GBP, Cloth or E-book.

***Inheritors of the Earth: How Nature Is Thriving in an Age of Extinction.** By Chris D. Thomas. 2018. Penguin UK. 320 pages, 9.99 GBP, Paper or E-book.

***Frog Pond Philosophy: Essays on the Relationship Between Humans and Nature.** Culture of the Land Series. By Strachan Donnelley. Edited by Ceara Donnelley and Bruce Jennings. Foreword by Frederick L. Kirschenmann. 2018. University Press of Kentucky. 266 pages, 80.00 USD, Cloth, Paper, or Web PDF, 30.00 USD, E-book.

The Biology of Urban Environments. Biology of Habitats Series. By Philip James. 2018. Oxford Univer-

sity Press. 320 pages, 95.00 CAD, Cloth, 45.95 CAD, Paper. Also available as an E-book.

Environmental Attitudes through Time. By R.J. Berry. 2018. Cambridge University Press. 276 pages, 39.95 CAD, Paper.

Natural Enemies: An Introduction to Biological Control. Second Edition. By Ann E. Hajek and Jørgen Eilenberg. 2018. Cambridge University Press. 452 pages, 56.95 CAD, Paper.

***Mark Catesby's Legacy: Natural History Then and Now: The Art and Science of our Environment and the Choice we Face in the Future.** By M.J. Brush and Alan H. Brush. 2018. Catesby Commemorative Trust. 191 pages and 32 original watercolour plates, 28.95 USD, Paper.

Darwin's Man in Brazil: The Evolving Science of Fritz Müller. By David A. West. 2018. University Press of Florida. 340 pages, 79.95 USD, Cloth, 26.95 USD, Paper. Cloth edition published in 2016.

The Wonderful Mr Willughby: The First True Ornithologist. By Tim R. Birkhead. 2018. Bloomsbury Publishing. 368 pages, 27.00 USD, Cloth, 18.90 USD, E-book.

Honeybee Hotel: The Waldorf Astoria's Rooftop Garden and the Heart of NYC. By Leslie Day. 2018. Johns Hopkins University Press. 208 pages, 22.95 USD, Cloth or E-book.

Still Waters: The Secret World of Lakes. By Curt Stager. 2018. W.W. Norton. 272 pages, 26.95 USD, Cloth.

News and Comment

Upcoming Meetings and Workshops

The Wildlife Society Annual Conference

The 25th Wildlife Society Annual Conference Meeting to be held 7–11 October 2018 at the Cleveland Convention Center, Cleveland, Ohio. Registration is cur-

rently open. More information is available at <http://twscconference.org>.

Student Conference on Conservation Science-New York

The 9th annual Student Conference on Conservation Science-New York to be held 24–26 October 2018 at the American Museum of Natural History, New York, New York. More information is available at [https://](https://www.amnh.org/our-research/center-for-biodiversity-conservation/convening-and-connecting/student-conference-on-conservation-science-new-york-sccs-ny)

www.amnh.org/our-research/center-for-biodiversity-conservation/convening-and-connecting/student-conference-on-conservation-science-new-york-sccs-ny.

North American Caribou Workshop

The 17th North American Caribou Workshop, organized by Environment and Climate Change Canada in partnership with Natural Resources Canada and a number of non-governmental organizations, to be held 29 October–2 November 2018 at the Delta Ottawa City

Centre, Ottawa, Ontario. The theme of the conference is: ‘Working Together’. Registration is currently open. More information is available at <http://www.nacw2018.ca/Homepage>.

James Fletcher Award for *The Canadian Field-Naturalist* Volume 131

The James Fletcher Award is awarded to the authors of the best paper published in a volume of *The Canadian Field-Naturalist* (CFN), and first started with Volume 130 (see 130: 285, <http://doi.org/10.22621/cfn.v131i3.2071>). The award is in honour of James Fletcher, founder of the Ottawa Field-Naturalists’ Club (OFNC) and the first editor of CFN’s earliest iteration, *Transactions of the Ottawa Field-Naturalists’ Club*. A subcommittee of the OFNC Publications Committee selected the top three papers in Volume 131 of CFN and the full committee made the final selection. The award for Volume 131 of CFN goes to:

Thomas Reimchen. Diverse Ecological Pathways of Salmon Nutrients Through an Intact Marine-terrestrial Interface. *Canadian Field-Naturalist* 131(4): 350–368. <https://doi.org/10.22621/cfn.v131i4.1965>

- This paper describes the flow of nutrients from salmon in spawning streams throughout the food web in both aquatic and riparian habitats in a protected reserve on Haida Gwaii, British Columbia. The paper is very clearly written, and an immense amount of work went into it.

Congratulations to Tom Reimchen for his excellent paper.

The other short-listed finalists were:

Marion Barbé, Louis Dubois, Jean Faubert, Martin Lavoie, Yves Bergeron, and Nicole J. Fenton. Range Extensions of 35 Bryophyte Species in the Black Spruce–Feather Moss Forest of Western Quebec, Canada. *Canadian Field-Naturalist* 131(3): 258–269. <https://doi.org/10.22621/cfn.v131i3.1901>

- This paper describes range extensions for an impressive number of bryophytes (35) in northern Quebec, and represents an impressive addition to the flora of the region.

Peter W. Hall, Paul M. Catling, Paul L. Mosquin, and Ted Mosquin. European Skipper Butterfly (*Thymelicus lineola*) Associated with Reduced Seed Development of Showy Lady’s-slipper Orchid (*Cypripedium reginae*). *Canadian Field-Naturalist* 131(1): 63–68. <https://doi.org/10.22621/cfn.v131i1.1952>

- This paper presents a clear, hypothesis-driven study, examining the influence of European Skipper Butterfly on the fitness of Showy Lady’s-slipper Orchid.

Congratulations to these finalists. We would also like to show our appreciation to all authors who chose to share their interesting and valuable field-based studies with the readers of Volume 131 of *The Canadian Field-Naturalist*.

WILLIAM D. HALLIDAY and JEFFERY M. SAARELA
OFNC Publications Committee

Francis Cook Appointed to the Order of Canada for his Exceptional Contributions to Canadian Herpetology and *The Canadian Field-Naturalist*

Francis Cook, former Editor-in-Chief and Associate Editor of *The Canadian Field-Naturalist* (CFN) and long-time and Honorary Member of The Ottawa Field-Naturalists' Club, was appointed to the Order of Canada on 29 June 2018. The Order of Canada is one of our country's top civilian honours, awarded in recognition of an individual's outstanding achievement, dedication to community, and service to Canada (Governor General of Canada 2018). In Francis' case, this was "For his dedication to the development of Canadian herpetology and for his lifelong contributions to a specialized publication in the field" (Governor General of Canada 2018).

Francis has contributed to the development of herpetology in Canada in many ways. Contributions include:

- his involvement with the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), chairing the COSEWIC subcommittee for amphibians and reptiles from 1981–1994 and serving subsequently as a COSEWIC reviewer;
- his tenure as Curator of the Herpetology Section for the Canadian Museum of Nature, where he helped increase the museum's herpetology collection from 14 000 to an impressive 133 000 specimens; and
- his contributions to the scientific literature, with 63 published scientific works on herpetology, including books, book chapters, monographs, and journal articles.

Francis has also made an exceptional contribution to CFN. When Francis Cook stepped down as Associate Editor in 2016 he completed 48 years of service to the journal. This included his 35-year tenure as Editor-in-Chief, a service three times longer than any other Editor in the 139-year history of CFN (and its predecessors). For a more detailed accounting of the contributions listed above, please see the Introduction to this Special Issue (Halliday and Seburn 2018) and Catling *et al.* (2016).

CFN offers its congratulations to Francis Cook for this well-deserved honour!

Literature Cited

- Catling, P., D. Brunton, J. Saarela, and F. Pope. 2016. Francis Cook steps down after long and distinguished service with the Ottawa Field-Naturalists' Club and the *Canadian Field-Naturalist*. *Canadian Field-Naturalist* 130: 385–387. <https://doi.org/10.22621/cfn.v130i4.1944>
- Governor General of Canada. 2018. Order of Canada Appointments, June 29, 2018. Accessed 12 August 2018. <https://www.gg.ca/document.aspx?id=17122&lan=eng>.
- Halliday, W.D., and D.C. Seburn. 2018. Introduction to the special issue on herpetology in Canada. *Canadian Field-Naturalist* 132: 1–3. <https://doi.org/10.22621/cfn.v132i1.2113>

AMANDA E. MARTIN

Assistant Editor – *The Canadian Field-Naturalist*

Minutes of the 139th Annual Business Meeting (ABM) of the Ottawa Field-Naturalists' Club 9 January 2018

Place and time: Neatby Building, Carling Avenue, Ottawa, Ontario, 7:00 pm
Chairperson: Diane Lepage, President

Over 50 attendees spent the first half-hour reviewing the minutes of the previous ABM, the financial statements, Treasurer's Report, and annual reports of the Ottawa Field-Naturalists' Club (OFNC) committees for 2016–2017. The meeting was called to order at 7:30 pm.

1. Minutes of the Previous Annual Business Meeting

It was moved by Lynn Ovenden and seconded by Gord Robertson that the minutes of the 138th Annual Business Meeting be accepted as distributed and published in *The Canadian Field Naturalist* (CFN).

Carried

2. Business Arising from the Minutes

Nil.

3. Communications Relating to the Annual Business Meeting

Nil.

4. Treasurer's Report by Ann Mackenzie

Ann presented the financial statements for the year ended 30 September 2017, which were reviewed by the accounting firm of Welch LLP. They show that OFNC's expenses were higher than revenues, as expected. The budget for 2017–2018, approved by the Board in October 2017, again forecasts a shortfall. Expenses will exceed revenues for the next several years as we employ the funds from the 2014–2015 bequest of Violetta Czasak to further the objectives of the OFNC. This will also result in a decline in our investment account and interest income.

Ann explained the deferral method used by OFNC for recognizing revenue from membership fees, grants, and CFN charges in the financial statements: it means recognizing revenue in the year in which the related expenses are incurred. The Club is fine-tuning the method for calculating these amounts. As a result, the financial statements show more deferred revenue this year than previous years, particularly for multi-year grants and CFN charges. Most subscription revenue for CFN volume 131 (2017) was deferred because only one issue of volume 131 was published by 30 September 2017. (A second issue was published in December 2017.) The by-issue review of CFN accounts also shows that CFN costs are rising but revenue is declining. In answer to a question about the print subscription, the price for

members has been \$30/year since 2010 and about 65 members get it.

This has been a year of transition for the role of Treasurer. Ann identified six other OFNC members who also volunteer much time to managing financial aspects of the OFNC. In order to simplify and ease this work, Ann and the new bookkeeper, Katryna Coltress, are using new accounting software procedures to register requests for payment and generate cheques. The number of bank accounts and internally restricted accounts have been reduced. Donation receipts are sent throughout the year and are computer generated. As well, three more members (Catherine Hessian, Tanja Schueler, and Bob Bergquist) have recently volunteered to handle cheque deposits, mail, Paypal transactions, and the charitable donation receipts.

In closing, Ann thanked Ken Young, the bookkeeper and accountants for their support.

Moved by Ann MacKenzie and seconded by Rémy Poulin, that the financial statements be accepted as fair representation of the financial position of the Club as of 30 September 2017.

Carried

5. Nomination of the Accounting Firm

Moved by Ann MacKenzie and seconded by Fenja Brodo, that the accounting firm of Welch LLP be contracted to conduct a review of the OFNC's accounts for the fiscal year ending 30 September 2018.

Carried

6. Committee Annual Reports

A summary of each report was given with an opportunity for questions and answers.

Moved by Lynn Ovenden and seconded by Barry Cottam, that the committee reports be accepted as distributed.

Carried

7. New OFNC Website

We have a new website, just launched on 8 January 2018, and built over the past two years by several

members and a local web company on a WordPress platform. OFNC members from several parts of the Club can contribute news and keep the content up-to-date. Annie Bélair provided a visual tour of the new website.

8. Nominations for Board of Directors positions

Relevant Excerpts from the OFNC Constitution (revised February 2000)

Article 8 – “The Council shall consist of the officers of the Club and up to eighteen additional members, all members of the Club.”

Article 12 – “The officers of the Club and other members of the Council shall be elected annually at the Annual Business Meeting. The nomination of sufficient persons for election to the various offices and membership of the Council shall be the responsibility of the Nominating Committee, which shall act in the manner prescribed in the By-Laws.

The Council shall, at the earliest possible date, appoint chairs and members of Standing and ad hoc committees and Editor and Business Managers, as required for club publications.”

Fenja Brodo presented the slate of candidates nominated to the Board of Directors for 2018:

EXECUTIVE COMMITTEE

Diane Lepage	President
Jakob Mueller	1 st Vice President and Chair, Events Committee
Lynn Ovenden	Recording Secretary
Treasurer	Ann MacKenzie

DIRECTORS

Fenja Brodo	Past President
Robert Cermak	Chair, Birds Committee
Owen Clarkin	Chair, Conservation Committee
Edward Farnworth	Representative, Fletcher Wildlife Committee

Catherine Hessian	Member-at-Large
Anouk Hoedeman	Chair, Safe Wings Ottawa
Diane Kitching	Representative, Macoun Field Club
Gordon Robertson	Chair, Education and Publicity
Jeff Saarela	Chair, Publications
Henry Steger	Chair, Membership
Eleanor Zurbrigg	Chair, Awards
Ken Young	Chair, Finance

EX OFFICIO:
Annie Bélair, Editor of *Trail & Landscape*
Dwayne Lepitzki, Editor of *The Canadian Field-Naturalist*

Moved by Fenja Brodo and seconded by Ernie Brodo that this slate of nominees be accepted as members of the Board of Directors of the OFNC for 2018.

Carried

Fenja acknowledged Rémy Poulin’s departure from the Board after several years of service as the Chair of Finance Committee and before that of Birds. She expressed pleasure at Ken Young’s return to the Board, as Chair of Finance. Committee chairs will be approved by the Board of Directors at the January 2018 meeting.

9. New Business and General Discussion

Bob Cermak asked which committee manages the OFNC facebook and twitter accounts. Currently, no committee is responsible for these social media. Gord Robertson serves as the Board’s liaison to the Facebook group. The twitter account is inactive.

10. Adjournment

Moved by Julia Cipriani and seconded by Gord Robertson that the meeting be adjourned.

Carried

LYNN OVENDEN
Recording Secretary

Annual Reports of OFNC Committees for October 2016–September 2017

Awards Committee

The Awards Committee manages the process to annually recognize those OFNC members and other qualified persons who, by virtue of their efforts and talents, are deserving of special recognition. In late 2016, nominations were received and evaluated (see awards criteria at <http://ofnc.ca/about-ofnc/awards>), resulting in nominees for five awards being recommended to the Board of Directors for approval. Biographies were written for each award winner for publication in the Club's journals and posting on the website. The awards were presented at the annual Awards Night in April 2017. The recipients' names, type of award (in brackets) and rationale for recognition follow below.

- Dr. John McNeill (Honorary Member): In recognition of lifetime contributions to Canadian botany and botanical nomenclature.
- Gordon Robertson (Member of the Year): For enthusiastic support of many activities of the Club.
- Sandra Garland (George McGee Service): For long and dedicated service to the Club and Fletcher Wildlife Garden projects.
- Richard Waters (Conservation – Member): For engaging students in designing and building nest boxes and installing them in appropriate habitat.
- The City of Ottawa (Conservation – Non-member): For modifying habitat to aid hatchling Snapping Turtles at the Britannia Conservation Area.

President Diane Lepage selected Carolyn Callaghan as the recipient of the 2016 President's Prize for her achievements in leading delivery of the CFN online with an innovative presence.

The committee thanks Mark Brenchley for helping with awards certificate design and printing. We thank Sandra Garland for technical support to the awards section of the club's website.

Awards Committee: Irwin Brodo, Julia Cipriani, Christine Hanrahan, Karen McLachlan Hamilton

ELEANOR ZURBRIGG, Chair

Birds Committee

The Birds Committee and the Club des Ornithologues de l'Outaouais organized another successful Ottawa Christmas Bird Count in December 2016. Though the official OFNC Falcon Watch is defunct at the moment, several members continue to keep an informal watch on the Heron Road nest site. Three more young Peregrines (*Falco peregrinus*) successfully fledged from this location this season. Safe Wings Ottawa has left the Birds Committee to become a standing committee of the club. This past summer saw the renewal of the Club's agreement with the Department of National

Defence for access to the causeway at the Shirley's Bay. New rules of access were put in place to ensure that club members will continue to enjoy this special privilege.

CHRIS TRAYNOR, Chair

Conservation Committee

The signature accomplishment of the OFNC Conservation Committee in 2017 was successfully spearheading a campaign, along with Ontario Nature, the David Suzuki Foundation, and other organizations, to end the Snapping Turtle (*Chelydra serpentina*) hunt in Ontario. The province had proposed limiting the hunt due to long-term, increased pressure on the Snapping Turtle population from habitat loss, road mortality, and hunting/poaching. Eliminating the hunt altogether is a simpler and more effective measure to help stabilize the declining Snapping Turtle population.

Members of OFNC-Conservation offer public outreach and active conservation work in the field. We led numerous conservation events this year, including: 25 guided public nature tours, six public lectures, six bio-inventories, and attendance/contribution to at least 10 conservation-related meetings. Our committee members continued to enthusiastically document wildlife near Ottawa and further afield with over 9000 observations entered into iNaturalist alone, and hundreds of records into other databases; many of these observations were of species of significant conservation interest.

As in previous years, we met regularly to discuss and plan actions regarding species of conservation concern (both threatened indigenous species, and emerging potentially invasive exotics) and habitat conservation/restoration projects. We collaborated on conservation work with a number of external organizations and other OFNC committees throughout the year.

Our committee gained two members this year: we were pleased to welcome Susan Gallinger, and Jakob Mueller (chair of OFNC-Events).

OWEN CLARKIN, Chair

Education and Publicity Committee

Several new projects were undertaken this year. One involved the installation of "storyboards" in eight locations around the Fletcher Wildlife Garden (FWG). The storyboards, designed by Mark Brenchley, were mounted on cedar posts; each can hold two removeable 8.5×10" posters (one in English, one in French) showing seasonal wildlife that may be seen near that post. Spring, summer, fall, and winter posters have been displayed in turn. Gord also developed a flyer with a scav-

enger-hunt-like list of animals and plants at FWG that visiting families can use when they visit.

Another new event this year was a springtime open house at the Interpretation Centre. Several members hosted about 40 visitors with drinks, cookies, and tours of the garden. The event was well publicized with an excellent radio interview by CBC's Giacomo Panico on the morning of the event.

This year we had only one application for sponsorship to the Youth Summit of Ontario Nature. She attended the event and gave an informative and illustrated presentation at Neatby of her stay. Lucy Patterson and Kathy Conlan were again judges at the annual Ottawa Regional Science Fair. They presented three awards (\$100 each) to the winning students.

We brought the OFNC display to a number of public events, including: City of Ottawa's Wildlife Speaker Series at CentrepoinTE and City Hall, Migratory Bird Day at Brewer Park, Bug Day at the Neatby Building, Gatineau Park Bioblitz, Earth Day at Hunt-Club Riverside Park Community Centre. Bug Day was especially successful this year with 100s of attendees visiting our microscope tables. A callout for volunteers yielded 12 enthusiastic OFNC members who assisted with identifying insects and observing specimens under the microscopes.

GORDON ROBERTSON, Chair

Events Committee

The Events Committee planned, coordinated or supported:

- 44 outings
- 9 monthly meetings, including the annual business meeting (This is normally 10; however, the March meeting was postponed, and later cancelled.)
- 5 other presentations or workshops
- 2016 Awards celebration at St. Basil's Church, held on 25 February.

The focus of outings, workshops, and monthly meetings included birds (18), general natural history (13), botany (7), insects (6), amphibians and reptiles (5), conservation (2), geology (2), photography (2), snails (1), lichens (1), and astronomy (1).

Unusually poor spring weather, including record-breaking precipitation and high, prolonged flooding of the Ottawa River, led to a number of postponements and cancellations. At least 6 events were rescheduled between March and June. A herpetological expedition to Morris Island and a mothing night in Larose Forest were among the cancellations.

Monthly meetings continue to be held in Salons A & B of the Neatby Building. Ensuring the availability of the venue has been an issue, causing the sudden postponements of the March and April meetings. The Jan-

uary business meeting was held at the Fletcher Interpretation Centre.

Committee members in 2017: Holly Bickerton, Julia Cipriani, Owen Clarkin, Hume Douglas, Margaret Hart, Bev McBride, and Jakob Mueller.

If you have ideas for events or would like to lead an outing or event, please contact Jakob Mueller (jm890_7 AT hotmail.com) or any other member of the committee.

JAKOB MUELLER, Chair

Finance Committee Annual Report 2017

Ann MacKenzie assumed the duties of Treasurer this year, and Rémy Poulin took over from her as Investment Manager. Work continued to have the bookkeeper take on additional functions and to take full advantage of technology.

The budget for 2017–2018 was prepared and presented to the Board in September for approval in October. While a shortfall of revenues over expenses of \$84 thousand is estimated, recent history suggests that the actual deficit will be less. Regardless, such a shortfall is considered manageable given the Club's overall strong financial position with investments totalling almost \$1.525 million at the end of September 2017.

The Club's accounting framework includes internally restricted funds that, over time, grew to eight in number. This is unnecessarily complex and, with the increasing use of separate account codes to track specific expenditures, provides little practical benefit. Consequently, in September, the Finance Committee proposed to the Board that the system be streamlined by reducing the number of these funds to three. The Board voted to approve this change starting in October 2017.

RÉMY POULIN, Chair

Fletcher Wildlife Garden

This year has been a very productive one at the Fletcher Wildlife Garden in spite of the very wet and cool start to the outdoor season. We recruited a large number of new volunteers and several new corporate and student groups helped with more physical tasks. Our work groups and individuals overseeing designated areas of the FWG, called nodes, combined to make a workforce that had a noticeable impact on the garden's appearance. In several areas, our work to remove invasive species (Dog-strangling Vine [*Vincetoxicum rossicum*], comfrey, buckthorn) is particularly evident. Over 5500 hours of volunteer time was spent maintaining the various parts of the Fletcher Wildlife Garden.

Visitors

The number of visitors, local, national, and international, has increased, and volunteers have received

many positive comments about the garden. The Fletcher Wildlife Garden is part of the Ottawa Garden Council and the Garden Promenade, which increased our visibility to the public and encouraged more visitors. High praise was received from the Ontario Environment Commissioner who toured the Fletcher Wildlife Garden early in the spring. Our Sunday afternoon open Resource Centre, the Back Yard Garden, the Butterfly Meadow, and the Amphibian Pond are popular points of interest. The addition of several information posts has helped visitors understand the wide variety of flora and fauna that can be found at the Fletcher Wildlife Garden.

Amphibian Pond

Work on the pond started early in the spring when the company contracted to dredge the pond returned to do contouring work, finish the pathway around the pond, and spread topsoil along the south bank. A large work group then planted over 2400 plants native wildflowers on the south bank. A chain-link fence was installed around the pond to protect the new plantings and prevent dogs from entering the pond. The plentiful rains ensured a good survival rate of the new plants; however, erosion meant that the new pathway had to be repaired several times to avoid accidents to walkers. Large quantities of Flowering Rush (*Butomus umbellatus*), an aquatic invasive species, returned in abundance and was removed manually throughout the summer.

Plant Sale

The plant sale was, again, a very successful event. A large number of old and new customers pushed our sales to over \$5000. This is one of our most labour-intensive activities, involving a large number of volunteers.

Fletcher Plaque

Parks Canada has erected a plaque on the Fletcher Wildlife Garden grounds to commemorate James Fletcher, Canada's first Dominion Entomologist and Botanist appointed in 1884. He oversaw the creation of the Arboretum and of a botanic garden to bring together all the native species of plants in Canada and to test the hardiness and adaptability of shrubs and trees growing in northern climates. James Fletcher was also a founding member of the Ottawa Field-Naturalists' Club.

Pollinator Project

With support from Friends of the Earth, Ottawa University students built and planted three raised pollinator beds at the FWG. These will be maintained as model "pollinator gardens in a box" to show visitors what plants can be grown in a small space to help pollinators.

TED FARNWORTH, Fletcher Wildlife Garden Committee

Macoun Club

The Committee organized the activities of the Macoun Field Club by telephone and e-mail. All four Committee members have been leaders with the Macoun Club for periods in the order of 10, 20, and 30 years, so matters of routine management are divided up into familiar patterns. Sixteen meetings were held indoors, with some presentations being made by outside speakers and others by Macoun Club leaders. There were 17 field trips, mostly to familiar places; one, to the Brewer Park pond, was a joint event coordinated with the OFNC.

The Club works closely with the National Capital Commission to monitor for, study, and attempt to control invasive plants in and near the Macoun Study Area in Stony Swamp. An illustrated record of all events was maintained on the Club's website (<http://ofnc.ca/programs/macoun-field-club>). Issue no. 71 of *The Little Bear* magazine was written and illustrated by Macoun Club participants.

For the second time, Macoun Club Committee members also volunteered to provide a field program to a Carleton University environmental-science class in the Macoun Club's Nature Study Area.

The Committee Chair, who has maintained the Macoun Club's independent web site for years, participated in the OFNC's Website Working Group, and kept a duplicate Macoun Club site on the new platform up-to-date throughout the year in case it should go live at any time.

ROBERT E. LEE, Macoun Club Committee

Membership Committee

The distribution of Club membership for 2017 on 30 September 2017 is shown in the table below, with the corresponding numbers shown in brackets for 30 September 2016. "Other" represent mostly affiliate organizations that receive complimentary copies of the Club's publications. There was an increase of 77 in membership in 2017 and showed a return to the upward trend in membership noted since 2013 with the exception in 2016. Members within 50 km of Ottawa comprised 738 of the membership of 848.

Families of children in the Macoun Club are given complimentary membership to encourage interest in the Club in the longer term. Macoun Club participation increased slightly in 2017.

HENRY STEGER, Chair

Publications Committee

The Publications Committee manages publication of the Club's scientific journal *The Canadian Field-Naturalist* (CFN), the Club's regional publication *Trail & Landscape*, and Special Publications. The committee also advises OFNC with respect to issues relating to research including research grants. Publications Com-

	CANADIAN		USA		OTHER		TOTAL	
	2017	2016	2017	2016	2017	2016	2017	2016
Individual	399	(358)	7	(8)	0	(0)	406	(364)
Family	316	(286)	0	(0)	1	(0)	316	(287)
Student	24	(19)	0	(1)	0	(0)	24	(20)
T&L	2	(2)	0	(0)	0	(0)	2	(2)
Honorary	25	(25)	0	(0)	0	(1)	26	(25)
Life	40	(41)	3	(3)	1	(1)	44	(45)
Other	24	(24)	0	(0)	1	(1)	25	(25)
Macoun Club	18	(16)					18	(16)
TOTAL	848	(771)	10	(12)	3	(3)	861	(784)

mittee meetings were held on 26 November 2016, 3 May 2017, and 4 October 2017. Committee members were Annie Bélair (Editor, *Trail & Landscape*), Dan Brunton, Carolyn Callaghan, Paul Catling, Barry Cottam (Book Review Editor, CFN), William Halliday (Journal Manager, CFN), Karen McLachlan Hamilton, Diane Kitching, Dwayne Lepitzki (Editor-in-Chief, CFN), Amanda Martin (Assistant Editor, CFN), Frank Pope, Jeff Saarela (Chair), David Seburn, and Eleanor Zurbrigg, who newly joined the committee.

Trail & Landscape

A major achievement this year was the launch of the re-designed *Trail & Landscape*. The first 50 volumes of the publication were printed primarily in black and white. The first two issues of volume 51 in 2017 were printed in colour in the “old format”, and the new all-colour design appeared in volume 51(3) (July–September 2017), a Special 50th Anniversary Issue. Work on the new design was led by *Trail & Landscape* Editor Annie Belair, and involved back-and-forth consultation with the Publications Committee. Feedback on the new format from Club membership has been extremely positive and encouraging.

The Canadian Field-Naturalist

Three issues of CFN were published: 130(3), 130(4), and 131(1). Beginning with 130(3), a new subheading was added to the cover page of the journal: “THE CANADIAN FIELD-NATURALIST: A JOURNAL OF FIELD BIOLOGY AND ECOLOGY”, to reflect the type of content we publish. Barry Cottam began his tenure as Book Review Editor with volume 130(2). Publication of 130(3) completed the Editor-in-Chief transition from Carolyn Callaghan to Dwayne Lepitzki. Ken Young, former chair of the Finance Committee, continued to manage CFN subscriptions, page charge invoices and budget tracking, and Eleanor Zurbrigg took over subscriptions in summer 2017. Copy editing of CFN papers was provided by Sandra Garland and Dr. John Wilms-hurst of Jasper, Alberta, a new member of the team.

Digital Object Identifiers (DOIs) were successfully implemented in CFN. A DOI is a unique alphanumeric identifier for a piece of content (e.g., a scientific paper) that is permanent and can be linked to on the web. DOIs have been assigned to all journal content as far back as 117(2), and beginning with 131(1), DOIs are included in the references. On the journal website, low resolution PDF files of CFN content going back to volume 125 were replaced with higher-resolution files, and all content is now posted in high resolution.

In 131(1) a new type of content was introduced in CFN. “Thematic Collections” are editor-selected compilations of previously published contributions to both CFN and *Trail & Landscape*, on a central theme with links to each article. The first Thematic Collection focussed on alvars in Canada.

Several papers published this year in CFN received regional and national media coverage, reflecting not only the important contributions to science published in the journal but also the importance and relevance of the journals content—and the Club as a whole—to broader society in Canada. These papers all deal with issues related to climate change: expanded range limits of boreal birds in the Torngat Mountains, northern Labrador (<http://dx.doi.org/10.22621/cfn.v131i1.1957>), reported on by The Telegram (St. John’s); expanded range limits of Beaver (*Castor canadensis*) into tundra habitat in Yukon and Alaska (<http://dx.doi.org/10.22621/cfn.v130i4.1927>), reported on by Radio Canada International and the Canadian Broadcasting Corporation (CBC); and interactions between Belugas (*Delphinapterus leucas*) and Killer Whales (*Orcinus orca*) in Hudson Bay (<http://dx.doi.org/10.22621/cfn.v130i4.1925>), reported on by the Canadian Press. Even content published over seventy years ago in CFN was mentioned in the media: in July 2017, the Ottawa Citizen reported that the arrival in Ottawa of Ring-billed Gulls (*Larus delawarensis*), which now are everywhere, was first reported in CFN in 1946. A 2016 *Trail & Landscape* article on long-term change in the pine grove vegetation at the Britannia Conservation Area, Ottawa,

was reported upon by the Ottawa Citizen (16 August 2017), and again several weeks later following the major windstorm that damaged many trees in the area.

Back issues of CFN were stored for decades in the Saunders Building, Central Experimental Farm, Agriculture and Agri-Food Canada, under the stewardship of W.J. Cody and, most recently, Paul Catling. In early 2017, the committee was informed that this storage space would no longer be available. Upon consolidation of the material, it was determined that these archives comprised volumes 109 to 123, with a few missing issues. In the current digital age, demand for hard copy back issues is practically nonexistent. Accordingly, a decision was made to divest the club of much of this space-consuming material. A small team of committee members convened, and subsets of available back issues were sorted and moved to the Red Barn on the Farm for temporary storage. This backlog material is freely available to anybody who wants it. The remainder of the back issues were recycled. More recent back issues (vols. 124 to present) are currently being stored by Wendy Cotie, our typographer who lays out CFN.

Ottawa Field-Naturalists' Club Research Grants

2017 was the third year of the Ottawa Field-Naturalists' Club Research Grants program. Research grants support field-based research activities that reflect and promote the Club's objectives within eastern Ontario and/or western Quebec, focussed particularly upon the Club's study area. A total of \$15 000 is available each year to fund research proposals. The call for proposals for 2017 awards was sent around in November 2016, with an application deadline of 15 January 2017. A sub-committee convened and chaired by Dr. Tony Gaston reviewed all proposals and recommended funding all four of them. The funding recommendations were submitted to the Board of Directors, who approved all of them. One applicant subsequently declined the funding, resulting in three projects being funded:

- Paul Catling, independent researcher. Changing status of terrestrial snails in Ottawa.
- Mary Ann Perron, Ph.D. candidate, University of Ottawa. Are urban ponds good wildlife habitat?
- David Seburn, Seburn Ecological Services. Identifying breeding locations of the threatened Western Chorus Frog (*Pseudacris triseriata*) in eastern Ontario.

JEFFERY M. SAARELA, Chair

Treasurer's Annual Report, 2017

The Financial statements for the year ended 30 September 2017 have been prepared by our accounting firm, Welch LLP based on a review they conducted of our financial records. We appreciate the considerable

assistance of Mark Patry and Eric Leibmann. We do not get our books audited.

The financial statements are on an accrual basis which results in deferrals of funds received, such as membership fees, to the extent that there is a benefit owing to others after the date of the financial statements. We are continuing to fine tune our method of calculating these amounts which has resulted in greater deferrals this year than previous years. For example the CFN received subscription revenue for Volume 131 (2017) but only one issue of that volume was published by September 30th. As a result 75% of the subscription revenue was deferred. Furthermore, we received more grants this year than previously. Since a large portion of these grants relate to projects in the future our deferred revenue related to contributions is also higher. Note 6 of the Financial Statements (available at <http://www.canadianfieldnaturalist.ca/index.php/cfn/article/view/2117/1999>) provides more detail.

The last payment from the Czasak bequest was in 2015 and since then we have been incurring losses. We will be seeing expenses exceeding revenues for the next several years as we employ the bequest to further the objectives of the Club. This will also result in a decline in our investment account and interest income. The budget for 2017–2018 was approved by the Board on 16 October 2017. It forecasts a shortfall of \$84 000. Our budgets tend to overstate our shortfall because many revenue sources are uncertain. The budget for 2016–2017 projected a deficit of \$114 000 when, in fact it was \$43 000.

Our investments are in conservative bonds with maturities spread over future years somewhat evenly. As we continue to incur deficits more of the investments will be liquidated to provide the necessary cash. Remy Poulin has been our investment manager in 2017 and Catherine Hessian will be assuming that responsibility in 2018. They work closely with our investment advisor, Sue Anderson at BMO Nesbitt Burns and follow the investment policy approved by the Board.

This was a year of transition as the role of Treasurer changed from Ken Young to myself on 10 January 2017. At the same time it was our first full fiscal year with a new bookkeeper, Katryna Coltress at Plus Associates, and new accounting software procedures. I am working to simplify the role of the Treasurer so that it can be undertaken without a huge time commitment. Part of that process is to use technology and programs to the greatest extent possible. Some of the changes are:

- a) The number of bank accounts has been cut from three to one.
- b) All requests for payments are electronic submissions with no paper and some are on automatic payment. Individual claimants scan their receipts before forwarding for payment.

- c) Cheques are generated from our accounting software, Quick Books, to fit in window envelopes.
- d) Donation receipts are sent throughout the year rather than year end and are computer generated. We are exploring sending them electronically while still meeting the CRA requirements.
- e) Treasurer assistants are helping with deposits and donation receipts.
- f) The number of internally restricted funds is being reduced to three from eight.

We are continuing to seek out ways to simplify the financial/administrative aspects of the club including subscription management for CFN and invoicing author charges.

As I have undertaken my treasurer duties I have been thankful for the generous support I received from the previous treasurer, Ken Young, and from the Board members, the Bookkeeper and the accountants who have been very patient with my learning curve.

ANN MACKENZIE, Treasurer

The Ottawa Field-Naturalists' Club Awards for 2017, presented February 2018

ELEANOR ZURBRIGG, IRWIN BRODO, JULIA CIPRIANI, CHRISTINE HANRAHAN, AND KAREN McLACHLAN
HAMILTON

On February 24th, 2018, members and friends of the Ottawa Field-Naturalists' Club (OFNC) gathered for the Club's Awards Night at St. Basil's Church in Ottawa to celebrate the presentation of awards for achievements in the previous year. Awards are given to members or non-members who have distinguished themselves by accomplishments in the field of natural history and conservation or by extraordinary activity within the Club.

Four Club awards were presented for 2017, for: (1) re-designing *Trail & Landscape*, (2) long time service for the Events Committee, (3) advocacy and science to ban the hunt of Snapping Turtles (*Chelydra serpentina*) in Ontario, and (4) nature-based education in Ottawa.

As well, a President's Prize was presented and a new award was announced—the James Fletcher Award—that is issued by the Publications Committee.

Member of the Year Award: Annie Bélair

This award recognizes a member judged to have contributed the most to the Club in the previous year.

Annie Bélair has been an active member since she joined in 2004, but in 2017 her contributions were exceptional.

When Annie became Editor of *Trail & Landscape* (T&L) in 2016, one of her goals was to revamp the publication, giving it a more contemporary look for its 50th anniversary in 2017. She began by looking at publications from other natural history clubs. Then mock-ups were produced by a professional graphic designer and reviewed by the Publications Committee. With these mock-ups as inspiration, and with the committee's suggestions in mind, Annie sprang into action. The result is the publication you see today.

Initially the plan was to create the new look by changing T&L to the current standard magazine-size format and to move away from its black-and-white style. The transformation was gradual, beginning with colour images (made possible by a generous bequest to the OFNC) in the first two issues of 2017. The complete reveal was seen in July's special anniversary issue where margins were reduced, creating less white space, titles were changed in size, and a new multi-coloured writing style was incorporated throughout. Some images now occupy an entire page while others bleed onto the fac-

ing one. And the front cover will be different with each issue, highlighting an article found within. The new version of T&L is quite eye-catching. Creating the makeover was no easy task. To produce the 79-page anniversary issue, Annie spent 8–12 hours each and every weekend day and 1–2 hours each night during the week for the entire month of May and the beginning of June. She formatted the articles she received, contacted Club members to acquire images, and even wrote articles herself to fill the gaps she saw with respect to content fitting for this special issue. The final version was one extremely large document that she had to split it into sections so it could be submitted to the printer electronically. Then she had to make sure all the sections were compiled correctly. It takes an extremely focussed individual to accomplish all this within a six week production window.

In 2017, Annie's contribution to the Club was not solely as Editor of T&L. She sat on the Board of Directors and was a member of the Publications Committee, where she contributed to all the meetings. She was also involved in the redesigning of the OFNC website, and continued to help with the Macoun Club and the Awards Night. Where did she find the time?

What a year it was for Annie, our Member of the Year.

(Prepared by Karen McLachlan Hamilton)

George McGee Service Award: Julia Cipriani

This award is given in recognition of a member who has contributed significantly to the smooth running of the Club over several years.

This year, Julia Cipriani is the recipient of the 2017 George McGee Service Award. Julia probably needs little introduction, for she has been involved with so many OFNC activities that she is well-known. Julia joined the

OFNC in 2004, and within a few years was volunteering her time and energy to any number of club projects and initiatives.

From 2007 to 2013, she was a keen volunteer with the Fletcher Wildlife Garden's Butterfly Meadow project, which relies heavily on dedicated people to maintain the habitat. In the earlier days, when Julia became

involved, the meadow was still in the process of being expanded and revamped, and Julia was instrumental in helping create the Butterfly Meadow we see today.

Earlier still, in 2006, Julia joined the OFNC Board of Directors, where she served for several years as a Member-at-Large. Later she re-joined the Board as Chair of the Events Committee from 2014 through 2016.

Julia has been a key participant in the very active Events Committee (previously, Excursions and Lectures) from 2007 to the present, both as a member, and as the Chair. Being extremely organized, she contributes greatly to the smooth operation of this committee. It is not unknown for her to arrange more than a dozen events a year, and as another member of the committee said, "We would not have the same number or breadth of events without the work she does". She is also ever on the lookout for people to serve as trip leaders, or to give presentations at the monthly meetings. Even at the Awards Night, she does not rest, but seeks out any potential new leaders or presenters willing to contribute their expertise. Julia says that she enjoys learning about the natural world, and this fuels her determination to continue looking for people who can introduce the beauty and wonder of nature to others. She says that being an extrovert and feeling comfortable talking to strangers helps! It is also her low-key but passionate approach that makes it hard for them to say "no". In addition, she gives tremendous encouragement to other committee members, and provides them with guidance and tools which enable them to be important

contributors to the Events Committee. Julia also attends almost every OFNC monthly meeting, and many of the field trips, helping to make sure they run smoothly. Furthermore, Julia has hosted all but one of the committee meetings at her house since 2012. And she provides not only a warm and welcoming atmosphere, but snacks too.

In addition to her busy engagement with the Events Committee, Julia was also very active with the Soiree/Awards Night from 2008 to 2016. Initially, she volunteered to help find gifts for the silent auction, visiting businesses such as Focus Scientific, Wild Birds Unlimited, and many more. Soon enough, however, she also began to take on more of a role in preparing the food for the Awards Night, and then, from 2011 to 2016, she purchased the food for the event, a not inconsiderable job, as well as continuing to help with preparation.

During Ann MacKenzie's term as OFNC President, Julia worked with her on ways to expand and engage membership. As part of this initiative, she co-facilitated several sessions seeking ideas on how to garner interest in the OFNC.

And last, but not least, Julia has been a keen member of the Awards Committee since 2009, providing valuable ideas and input, writing citations, and helping with a variety of necessary tasks.

For all these reasons and more, we are pleased to honour Julia Cipriani with the 2017 George McGee Service Award.

*(Prepared by Christine Hanrahan,
using much of Jakob Mueller's nomination)*

Conservation Award – Member: David Seburn

This award recognizes an outstanding contribution by a member in the cause of natural history conservation in the Ottawa Valley, with particular emphasis on activities within the Ottawa District.

This year David Seburn is the recipient of the Conservation Award – Member for his determination and contributions to the effort to ban the Snapping Turtle hunt in Ontario.

David Seburn spent 20 years as an independent amphibian and reptile ecologist, and is now the freshwater turtle specialist for the Canadian Wildlife Federation. He is a member of the Ottawa Field-Naturalists' Conservation and Publications committees and chair of the Canadian Herpetological Society's conservation committee.

In 2012, David was awarded the Ottawa Field-Naturalists Club's award for Conservation for his significant efforts in turtle research and conservation in the Ottawa area. He was part of a group that unsuccessfully lobbied the Ontario government to ban the Snapping Turtle hunt at that time.

The Ontario government designated the Snapping Turtle as a Species at Risk, but held on to their position to retain the hunt. When the Ontario government opened comments on changes to the provincial hunting

regulations in 2016, there was renewed interest in trying to end the hunt. David held his position that the hunt was not based on science and publicized the risks Snapping Turtles face, including habitat loss, persecution, and road kill. It can take 20 years or more for an individual turtle to mature, making it difficult for populations to rebound from losses. Adult females are particularly vulnerable to road kill during the nesting season when they are looking for places to lay their eggs. When females do successfully lay eggs, their nests are often raided by foxes, Raccoons (*Procyon lotor*), and other predators.

David worked with many naturalist organizations, including our own Ottawa Field-Naturalists' Club and Ontario Nature to engage and motivate others to ask the Ontario government to end the Snapping Turtle hunt. He helped keep the short-sightedness of the hunt in the news and on social media. The Ontario government received more than 11 000 comments calling for the end of the Snapping Turtle hunt, and in early 2017 the hunt was finally banned. The turtle is currently listed as a species of "Special Concern".

On their website, Ontario Nature acknowledges that, "It was a collaborative journey of dogged determination, fueled by letters to ministers, petitions, reports,

opinion editorials, action alerts, blogs, and social media campaigns. When the going got tough, the fair and informed coverage by the press and by the Environmental Commissioner of Ontario helped immensely to buoy weary spirits and keep the issue in the public eye”.

David was a key player in the process. He used his powers of persuasion via the internet to keep the issue in the news. A brief search of the subject will give rise to several links describing his tenacious effort to keep the hunt in view.

It is for his promotion and advocacy to ban the hunting of Snapping Turtles in Ontario, that the OFNC is pleased to present David Seburn with the Conservation Award for a Member for 2017.

(Prepared by Julia Cipriani. Material from the Ontario Nature website was accessed January 2018, <http://www.ontarionature.org/connect/blog/at-long-last-an-end-to-the-snapping-turtle-hunt>)

Mary Stuart Education Award: Teachers of Regina Street Alternative School

This award is given to a member, non-member, or organization, in recognition of outstanding achievements in the field of natural history education in the Ottawa Region.

We at the OFNC firmly believe that the well-being of the natural world in the near and distant future lies in the love of nature that is developed in the young. Unless young people are fortunate enough to have access to natural history clubs like the Macoun Field Club, their appreciation of nature is usually acquired through experiences they have with their family and the lessons they learn at school, especially if they have teachers such as those at the Regina Street Alternative School.

This school, situated adjacent to Mud Lake in the Britannia area, has over the past six years developed an extraordinary program of general learning based on exposing their students to a variety of outdoor experiences. Essentially, the teachers have made Mud Lake part of their school. The teachers have both brought nature into the classroom and used the natural environment as the classroom.

Robert James, the principal of the school, describes it as follows: “On a weekly basis students go down to Mud Lake with an educational focus. It could be anything from a math activity to a writing exercise. Students are able to share a common experience in a natural setting and take control of their own learning”. For example, math classes explored mathematical patterns in nature and then found out how to determine the height of a tree using geometry, how to display data

results using graphs, and how to calculate probabilities with regard to the occurrence of natural events. Social Studies classes included drawing maps, finding out how various levels of government preserve natural spaces, and First Nations connections with the environment.

The outdoor projects continue into the school hallways with artwork and conversations, undoubtedly inspiring other students to explore the area. Kathleen Turner, of the MacSkimming Outdoor Education Centre, notes that, “The staff at Regina ... have learned along with their students. Their curiosity and motivation to explore the natural environment has not only brought the students’ learning to life, but has also helped shape an observant, kind, and curious community of students”. The students have, in turn, inspired their parents’ interest in the natural world, not surprising because, as we all know, we often learn much from our children.

The imaginative and resourceful teachers at Regina Street School have become mentors throughout the Ottawa-Carleton District School Board based on their experience with inquiry-based lesson plans and classroom management techniques using outdoor spaces. Because of their inspired and inspiring leadership in natural history education, the elementary school teachers at the Regina Street Alternative School are the 2017 winners of the OFNC’s Mary Stuart Education Award.

(Prepared by Irwin Brodo)

President’s Prize: Adrienne Jex and Greg Lutick

This award is given at the President’s discretion in recognition of a member for unusual support of the Club and its aims.

For 2017, I would like to acknowledge the service given by Adrienne Jex and Greg Lutick.

Adrienne and Greg are the resourceful and dependable couple who about four years ago took over the refreshment table at our club’s monthly meetings, shortly after we moved into the Neatby Building facility. They have successfully coped with a difficult situation—the water is far away and plugs for the electric kettles are inconvenient and they need to come early to heat the water and set up their table. They invested in

equipment to keep the brewed coffee hot and at most monthly meetings we are treated to their homemade goodies, the most imaginative being the cupcake moths that they made for the talk on Moths and Nothing. These were particularly relished. When Adrienne and Greg cannot make a monthly meeting, they see to it that somebody else is covering for them.

For their dependability, creative imagination, and for adding a special touch to our monthly meetings, I wish to award Adrienne and Greg the President’s Prize for 2017.

(Prepared by Fenja Brodo and Diane Lepage, President)

James Fletcher Award: Diana Bizecki Robson, John H. Wiersema, C. Barre Hellquist, and Thomas Borsch

New in 2017, the James Fletcher Award recognizes the best paper published in *The Canadian Field-Naturalist* in a particular volume, commencing with volume 130 (2016). The award is administered by the Publications Committee of The Ottawa Field-Naturalists' Club.

The first recipients of this new award are Diana Bizecki Robson, John H. Wiersema, C. Barre Hellquist, and Thomas Borsch for their paper entitled "Distribution and ecology of a new species of water-lily, *Nymphaea lorianna* (Nymphaeaceae), in Western Canada", *Canadian Field-Naturalist* 130(1): 25–31. <https://doi.org/10.22621/cfn.v130i1.1787>. The paper describes an

extensive field investigation of the distribution and ecology of a newly described aquatic plant species endemic to the Prairie Boreal Region of Canada. It represents foundational research on a new taxonomically important species and will be referred to for decades to come.

Congratulations to authors Robson, Wiersema, Hellquist, and Borsch, who have been sent personal copies of the award certificate.

(Prepared by Annie Bélair based on material from Dan Brunton and Jeffery Saarela, see Canadian Field-Naturalist 131(3): 285. <https://doi.org/10.22621/cfn.v131i3.2071>)

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The CANADIAN FIELD-NATURALIST

A JOURNAL OF FIELD BIOLOGY AND ECOLOGY



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**SPECIAL ISSUE: STUDIES ON CANADIAN AMPHIBIANS AND REPTILES
IN HONOUR OF DR. FRANCIS COOK. PART II.**

Published by THE OTTAWA FIELD-NATURALISTS' CLUB, Ottawa, Canada

The Ottawa Field-Naturalists' Club

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Patron

Her Excellency the Right Honourable Julie Payette, C.C., C.M.M., C.O.M., C.Q., C.D.
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The objectives of this Club shall be to promote the appreciation, preservation and conservation of Canada's natural heritage; to encourage investigation and publish the results of research in all fields of natural history and to diffuse information on these fields as widely as possible; to support and cooperate with organizations engaged in preserving, maintaining or restoring environments of high quality for living things.

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The Thomas H. Manning fund, a special fund of the OFNC, established in 2000 from the bequest of northern biologist Thomas H. Manning (1911–1998), provides financial assistance for the publication of papers in the CFN by independent (non-institutional) authors, with particular priority given to those addressing arctic and boreal issues. Qualifying authors should make their application for assistance from the Fund at the time of their initial submission.

COVER: Studies on Canadian Amphibians and Reptiles in Honour of Dr. Francis Cook. Centre: Dr. Francis Cook (photo: Brian Coad). See The Publications of Francis Cook on pages 99–102. The inset photos (clockwise from top right) are: Red-bellied Snake (*Storeria occipitomaculata*; photo: Nick Cairns; see article on pages 150–166), Western Chorus Frog (*Pseudacris triseriata*; photo: Jonathan Choquette; see article on pages 176–190), Western Painted Turtle (*Chrysemys picta belli*; photo: Kelsey Marchand; see article on pages 108–119), Long-toed Salamander (*Ambystoma macrodactylum*; photo: Cynthia Paszkowski; see article on pages 168–175), Spiny Softshell (*Apalone spinifera*; photo: Christina Davy; see article on pages 120–121).

The publications of Francis Cook

The introduction to the first part of this two-part special issue, which is dedicated to Dr. Francis Cook, provided an overview of Francis's lengthy career as a herpetologist and Editor of *The Canadian Field-Naturalist* (Halliday and Seburn 2018). Here, we outline the published contributions Francis has made over many decades.

Francis has been an active researcher and science communicator for more than 50 years. His first two papers, co-authored with Sherman Bleakeney, were published in 1957 (Bleakney and Cook 1957a,b). Major publications include results from his master's thesis on the herpetofauna of Prince Edward Island (Cook 1967), results from his doctoral dissertation on the contact zone of American Toads (*Anaxyrus americanus*) and Canadian Toads (*Anaxyrus hemiophrys*) in Manitoba (Cook 1983), and the first book-length introduction to the amphibians and reptiles of Canada (Cook 1984a,b). Francis also wrote one of the earliest summaries of rare and endangered amphibians and reptiles in Canada (Cook 1970a). More recently, he wrote a detailed history of herpetology in Canada (Cook 2007a).

The following is a list of Francis's peer-reviewed publications, his non-peer reviewed herpetological publications, and selected other publications. We have excluded book reviews (almost 100 published since 1962), tributes, and various editorial material from his lengthy tenure editing *The Canadian Field-Naturalist*. This list includes an impressive 101 publications: a clearly significant contribution to the field of herpetology in Canada.

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Oviposition and subsequent depredation of Snapping Turtle (*Chelydra serpentina*) nests in fresh asphalt

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Abstract

On 28 June 2009, three Snapping Turtle (*Chelydra serpentina*) nests were found oviposited in fresh asphalt beside a bridge in Algonquin Provincial Park, Ontario. One nest was excavated immediately; the other two were left untouched. The two nests left *in situ* were revisited on 28 July when it was discovered that one nest had been depredated by an unknown predator. Evidence of the third nest was obliterated by tracks of large mammals crossing the bridge. These observations suggest that predators find turtle nests despite the strong odour of asphalt. To examine potential negative impacts of asphalt on turtle eggs, five clean Snapping Turtle eggs, collected elsewhere in Algonquin Provincial Park, were buried in asphalt on 28 July. After eight days, the translocated eggs had obvious staining and contained 0.081–0.376 µg/g (wet weight) polycyclic aromatic hydrocarbons (PAHs), presumably resulting from asphalt exposure. The risk of exposure to PAHs or other chemicals associated with asphalt is unknown, but the levels of PAHs in these eggs appeared lower than those associated with acute toxicity.

Key words: Snapping Turtle; *Chelydra serpentina*; asphalt; polycyclic aromatic hydrocarbons; oviposition; predation; Algonquin Provincial Park; Ontario

Introduction

In landscapes with substantial human activity, Snapping Turtles (*Chelydra serpentina*) and other freshwater turtle species oviposit in a variety of artificial substrates, such as dams, railway and road embankments, roadsides, vegetable gardens, compost, coal ash, and sand or gravel pits (Loncke and Obbard 1977; de Solla *et al.* 2001; Nagle *et al.* 2001; de Solla and Fernie 2004; Aresco 2005). In many parts of their range, most female Snapping Turtles nest in artificial substrates, because natural areas might not be available, and turtles may travel considerable distances to nest on embankments or dams (Obbard and Brooks 1980).

The use of artificial or anthropogenically modified substrates by turtles can have consequences for the developing embryo (e.g., Nagle *et al.* 2001; de Solla and Martin 2007), and possibly for egg predators and the nesting female turtles. Here we report oviposition by three Snapping Turtles in asphalt, depredation of one of those nests by an unknown predator, and the absorption of polycyclic aromatic hydrocarbons (PAHs) in turtle eggs.

Methods

Field-site observations

A search was conducted for Snapping Turtle nests in Algonquin Provincial Park, Ontario, to collect eggs for a toxicological study (internal Animal Care protocol 0902 by Environment Canada) examining their absorption of polycyclic aromatic hydrocarbons (PAHs). Al-

gonquin Provincial Park has previously been used as a source of eggs for experiments to examine toxicity of soil-borne contaminants (e.g., de Solla and Martin 2007). Roadsides were searched for turtle nests, which were excavated and the eggs removed.

During the afternoon of 28 June 2009 on the road along Costello Creek south of Lake Opeongo (45.61 6815°N, 78.344354°W), three Snapping Turtle nests in fresh asphalt were observed (Figure 1). The nests were presumed to be about two weeks old, given the normal period of oviposition of Snapping Turtles in Algonquin Provincial Park. The nests were found by S.R.de S. beside a temporary bridge, newly installed as an emergency repair to keep the road open after damage to a culvert from spring runoff. “Cold patch” was used along the sides of the road to stabilize the bridge and reduce erosion from the damaged culvert (B. Steinberg pers. comm. 15 November 2010). Cold patch is a combination of asphalt and stone or gravel, which is mixed with a solvent (e.g., kerosene, diesel, or gasoline of varying composition) to make the asphalt pliable at low temperatures (Speight 2015). The asphalt along the sides of the bridge was not compacted and, thus, was loose to the touch. The smell of petroleum product was obvious. One nest was on the west side and two were on the east side of the bridge, on 45° slopes within ~60 cm of the road surface; consequently, there was no risk of tires running over the nests. All three nests had the classic mound and trough characteristics of Snapping Turtle nests (Figure 1) and were easy to

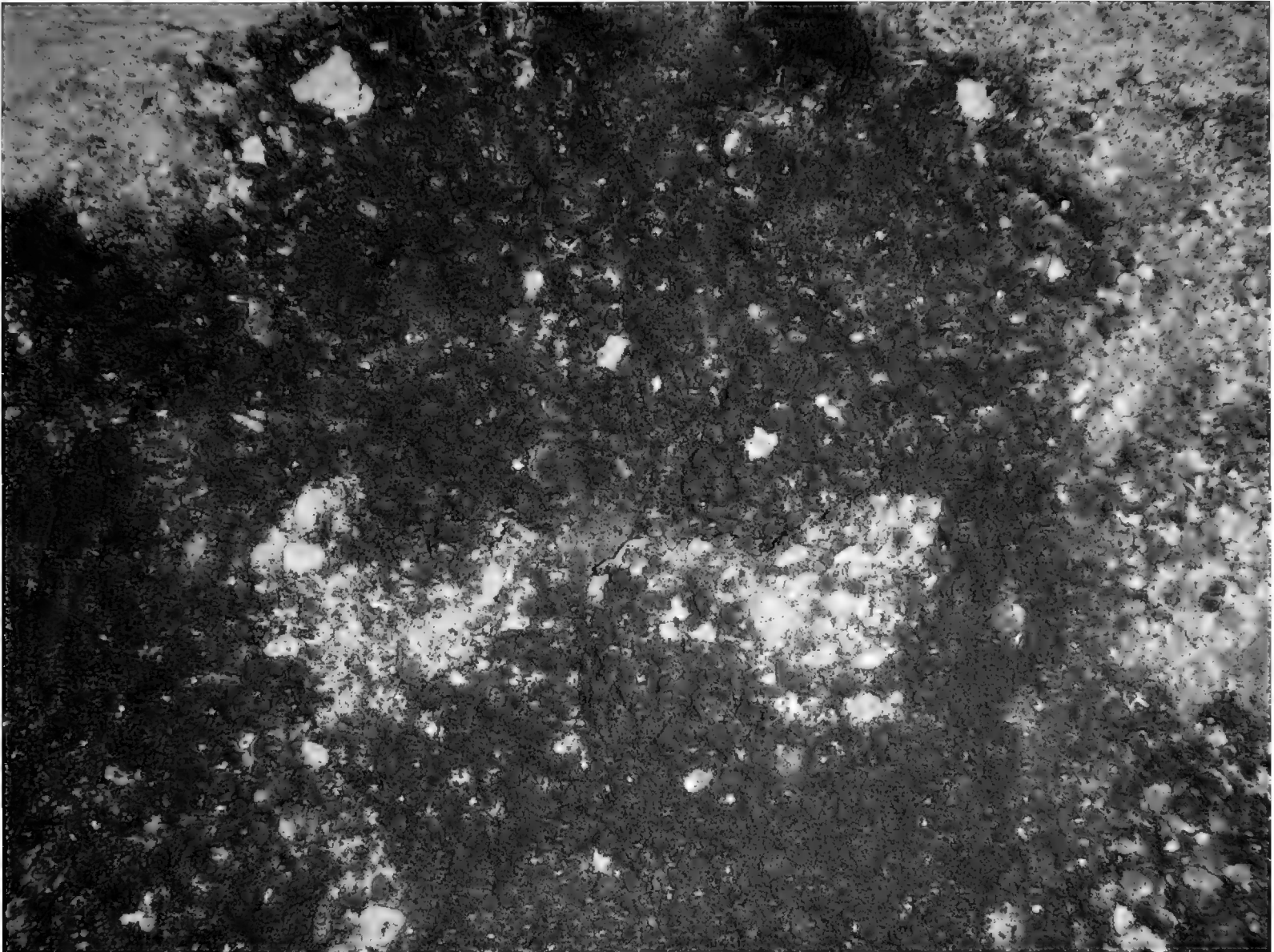


FIGURE 1. Snapping Turtle (*Chelydra serpentina*) nest deposited in “cold patch” asphalt mixture, beside a bridge in Algonquin Provincial Park, Ontario, 28 June 2009. Photo: Shane de Solla.

spot. This bridge was a known nesting area and Snapping Turtle nests in gravel and sand at this culvert were often depredated in previous years (S.R.de S. pers. obs.).

One nest was excavated immediately, whereas the other two were left untouched. Because the asphalt along the side of the bridge embankment was soft, there was little difficulty digging with a hand shovel. The excavated clutch was beneath the asphalt layer in the sand foundation of the embankment, although a considerable amount of asphalt was mixed with the sand substrate, such that the eggs were directly exposed to asphalt. All excavated eggs displayed black speckled stains (Figure 2), presumably resulting from direct exposure to the asphalt. The asphalt was very sticky and left a thick oily residue on the nitrile gloves used during nest excavation. The excavated eggs were removed from the site, but were unavailable for testing for logistic reasons.

On 28 July 2009, the site was revisited to remove eggs from the two remaining nests for artificial incubation to determine hatching success. One of the nests had been depredated and egg shells were found in the excavated cavity. Furthermore, numerous holes in the asphalt in the general area were observed, consistent with mammalian depredation attempts on turtle nests.

The third clutch was no longer visible, largely because of surficial disturbance by numerous animals, probably Moose (*Alces americanus*), walking over the bridge embankment. Attempts to find the missing clutch were ceased to minimize further disturbance to the asphalt. Unlike the nest that was excavated just after oviposition on 28 June, the depredated nest cavity was completely within the asphalt with little sand visible and, in the area of the lost nest, the asphalt was deeper than a typical Snapping Turtle nest cavity (i.e., deeper than 10–15 cm; Congdon *et al.* 2008). Consequently, those eggs would have had greater exposure to asphalt than the previously excavated nest.

Control eggs for an unrelated project from a separate Algonquin site were used to measure PAHs. Five eggs were buried on 28 July in fresh asphalt at a depth of about 12 cm, which is within the typical depth of a Snapping Turtle nest cavity (Congdon *et al.* 2008). On 5 August, the eggs were removed and sealed in a clear plastic sandwich bag. The eggs that were excavated had obvious staining, substantial black speckling, and an odour of asphalt (Figure 2). Samples of asphalt and sand under the asphalt were also collected and sealed in a plastic bag. They were brought to the Canada Centre



FIGURE 2. Snapping Turtle (*Chelydra serpentina*) egg showing black stains after eight days incubation in “cold patch” asphalt in Algonquin Provincial Park, Ontario. Photo: Shane de Solla.

for Inland Waters in Burlington the same day and the eggs, asphalt, and soil were placed in a -80°C freezer.

PAH analysis

The five eggs and soil and asphalt samples were sent to Maxxam Analytical (Mississauga, Ontario, Canada) for measurement of PAH concentrations using gas chromatography in selective ion monitoring mode, based on United States Environmental Protection Agency (EPA) method 8270. Eighteen PAHs (Table 1), including the 16 that are considered priority PAHs by the EPA, were measured in all samples. Reportable detection limits (RDLs) ranged from 0.005 to 0.02 $\mu\text{g/g}$ in turtle eggs and sand and from 0.1 to 0.4 $\mu\text{g/g}$ in asphalt.

Results and Discussion

The concentrations of six PAHs were found to be above RDLs and that of 1- and 2-methylnaphthalene was highest relative to the other PAHs in the eggs (Table 1). The concentration of all PAHs in eggs ranged from 0.081 to 0.376 $\mu\text{g/g}$ (wet weight). These findings support those of de Solla and Martin (2011) that Snapping Turtle embryos can directly absorb potentially harmful contaminants from material around the nest cavity. The turtles were only exposed to PAHs from the

substrate for eight days and, thus, the amount of PAHs absorbed may have been appreciably larger after the full incubation period and may have resulted in more toxicity than what was observed.

Three observations reported here are of note. First, Snapping Turtles will select nesting substrates, including asphalt, where there is some risk of exposure of eggs to toxic chemicals. Second, predators, presumably mammals (e.g., skunks, Raccoons [*Procyon lotor*], foxes, etc.) are capable of detecting turtle eggs that are buried under a substrate that is pungent to a human nose. Third, turtle eggs may absorb chemicals from asphalt.

We speculate that the asphalt was attractive to the turtles likely because of its high temperature at the time the females were selecting their oviposition site or because of the lack of covering vegetation. At northern latitudes, female Snapping Turtles select exposed locations with relatively warmer substrate temperatures to oviposit than turtles at more equatorial latitudes that select shadier, cooler substrates (Ewert *et al.* 2005), and they also prefer landscapes with short or little vegetation (Kolbe and Janzen 2002). Soil composition may not be as important in the choice of oviposition site (Hughes and Brooks 2006); Snapping Turtles are known to oviposit in sand, clay, wood chips, beaver lodges and

TABLE 1. Concentrations of polycyclic aromatic hydrocarbons (PAHs) in Snapping Turtle (*Chelydra serpentina*) eggs buried in asphalt from 28 July to 5 August 2009. PAHs in asphalt and in sand immediately below asphalt are also reported.

Type of PAH	Concentration of PAHs, µg/g wet weight						
	Eggs					Sand (RDL)	Asphalt (RDL)
	1	2	3	4	5		
Acenaphthene	ND	ND	ND	ND	ND	ND (0.01)	0.6 (0.2)
Acenaphthylene	ND	ND	ND	ND	ND	ND (0.005)	ND (0.1)
Anthracene	ND	ND	ND	ND	ND	ND (0.005)	0.5 (0.1)
Benzo(a)anthracene	ND	ND	ND	ND	ND	ND (0.01)	ND (0.2)
Benzo(a)pyrene	ND	ND	ND	ND	ND	ND (0.005)	0.1 (0.1)
Benzo(b/j)fluoranthene	ND	ND	ND	ND	ND	ND (0.01)	ND (0.2)
Benzo(g,h,i)perylene	ND	ND	ND	ND	ND	ND (0.02)	0.5 (0.4)
Benzo(k)fluoranthene	ND	ND	ND	ND	ND	ND (0.01)	ND (0.2)
Chrysene	ND	ND	ND	ND	ND	ND (0.01)	ND (0.2)
Dibenz(a,h)anthracene	ND	ND	ND	ND	ND	ND (0.02)	ND (0.4)
Fluoranthene	ND	ND	ND	ND	ND	0.006 (0.005)	0.2 (0.1)
Fluorene	0.007	0.008	0.006	ND	ND	ND (0.005)	1.5 (0.1)
Indeno(1,2,3-cd)pyrene	ND	ND	ND	ND	ND	ND (0.02)	ND (0.4)
1-methylnaphthalene	0.110	0.130	0.081	0.034	0.037	— (0.005)	—
2-methylnaphthalene	0.140	0.170	0.097	0.037	0.044	— (0.005)	—
Naphthalene	0.051	0.061	0.036	0.010	0.020	ND (0.005)	1.5 (0.1)
Phenanthrene	0.006	0.007	0.005	ND	ND	ND (0.005)	3.2 (0.1)
Pyrene	ND	ND	ND	ND	ND	0.009 (0.005)	0.7 (0.1)

Note: — = no data, ND = not detected, RDL = reportable detection limit.

dams, gravel, vegetable gardens, grass fields, and other substrates (Robinson and Bider 1988; de Solla *et al.* 2001; Congdon *et al.* 2008).

Road and habitat types may influence predation patterns. Although some believe that mammalian predators find turtle nests primarily through visual cues (e.g., Strickland *et al.* 2010), they are more generally assumed to use olfactory cues (Spencer 2002; Burke *et al.* 2005). Regardless of the mechanism(s) predators use, it is evident from our observations that they are capable of finding turtle nests in substrates containing chemicals that can interfere with olfactory senses and substrates with non-typical physical structure that can interfere with visual senses. Predators may even prefer unnatural habitats, such as roadsides, for hunting (Mata *et al.* 2017).

Snapping Turtles can spend substantial time selecting oviposition sites and appear to select substrate and environmental conditions that are suitable for egg development, but they clearly sometimes select substrates or conditions that may result in exposure to contaminants or other stressors. For example, female Snapping Turtles have been observed laying eggs in compost that was sufficiently hot to kill both the eggs and nesting turtles (de Solla *et al.* 2001). Reptiles sometimes oviposit in agricultural fields (Rauschenberger *et al.* 2004; de Solla and Martin 2007), in substrates that have been exposed to oil (Van Meter *et al.* 2006), or coal-ash-contaminated soils (Nagle *et al.* 2001).

Although Snapping Turtle eggs from a site contaminated with heavy metals and PAHs had lower hatching success and increased deformities relative to controls (Bell *et al.* 2006), the effect of PAHs and oil on turtle egg development is less clear. Exposure to both

oil and PAHs (through topical application to the egg-shell) increased deformity rates in turtle eggs from Algonquin Provincial Park (Van Meter *et al.* 2006). Although turtle eggs are capable of absorbing PAHs from soil contaminated with Arabian light crude oil (after exposure of up to 1 L of 10 g oil/L water in soil, eggs contained up to 0.56 µg/g of total PAHs), PAH exposure did not affect either hatching success or deformity rate (Rowe *et al.* 2009). Incidents of oviposition in asphalt as described here are presumably not common, but turtles frequently use roadsides for oviposition.

Reptiles may be exposed to PAHs through avenues other than contaminated soil. Studies have discovered the presence of PAHs in wild reptiles, but there are few studies that illustrate how PAHs affect health and development. PAHs were found in wild Loggerhead Sea Turtle (*Caretta caretta*) plasma samples and correlated with electrolyte levels as well as blood enzymes (Camacho *et al.* 2013). In addition, total proteins, albumin, globulins, and creatinine were positively correlated with PAHs. The authors suggested that these correlations could reflect altered kidney function. In a separate study, significant levels of PAHs were found in various tissues, predominantly in skin and kidney samples of two species of sea snakes (Sereshk and Bakhtiari 2014). Partial life cycle PAH exposure studies would be beneficial in determining deleterious effects in reptiles.

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Spatial ecology and multi-scale habitat selection by Western Painted Turtles (*Chrysemys picta bellii*) in an urban area

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Abstract

As urban centres expand, knowledge on the habitat and space use of native wildlife, particularly long-lived species, is required for proper management. Our objective was to understand space requirements and key habitat features necessary for long-term persistence of Western Painted Turtles (*Chrysemys picta bellii*) living in a Canadian urban park. Using radio telemetry, we examined seasonal habitat selection and space use over two years, 2015–2016 ($n = 23$), and 2016–2017 ($n = 29$) in Regina, Saskatchewan. Daily movements and home ranges of males and females were smaller during emergence than during nesting or post-nesting phases of the active season. Turtles inhabiting marsh sites had 2- and 4-times larger daily movements and home ranges compared to turtles inhabiting the creek. Turtles selected the shoreline habitat over urban/parkland and open water. Turtles used marsh-shoreline habitats non-randomly, selecting accessible shoreline with large trees in the active season. In contrast, turtles used creek-shoreline habitat according to availability. Overwintering sites selected by turtles were warmer and deeper than random available sites, with no difference in dissolved oxygen level. However, water was hypoxic for most overwintering sites. Our results show that turtles range widely, requiring 20–60 ha throughout the year. Urban park areas should be managed to provide accessible shorelines with a combination of cover and open basking areas. Critically, careful attention needs to be paid to managing water depth so that over-wintering sites remain viable.

Key words: *Chrysemys picta bellii*; Western Painted Turtle; habitat selection; urban ecology; radio telemetry

Introduction

Currently, more than 80% of Canadians reside in urban centres (Statistics Canada 2011). As a result, urban habitats are becoming increasingly fragmented and urban planners are challenged with designing and maintaining urban parks that can sustain healthy, native wildlife populations. Turtles have long life histories, characterized by slow somatic growth rates and late age at maturity, leading to slow population growth (Brooks *et al.* 1990). Small changes to the aquatic and terrestrial habitats of turtles, such as draining, dredging, and shoreline development, can affect their survival. Increases in adult mortality by even 2–3% per year can lead to drastic population declines and possible local extinction (Congdon *et al.* 1993; Gibbs and Shriver 2002). Urbanization impacts turtle populations by decreasing genetic diversity (Rubin *et al.* 2001), restricting aquatic mobility (Bennett *et al.* 2010), increasing adult mortality (Marchand and Litvaitis 2004; Aresco 2005; Gibbs and Steen 2005; Steen *et al.* 2006), increasing human disturbance (Pittfield and Burger 2017), and increasing rates of nest predation (Baldwin *et al.* 2004; Marchand and Litvaitis 2004). All of these factors are exacerbated at northern latitudes where climate may be an additional factor affecting turtle population parameters (i.e., shorter growing season, slowed annual somatic growth rate, further delayed age at maturity).

Previous studies have focussed on the detrimental impacts of urbanization for turtle population persistence; however, few studies examine critical features influencing persistence in urban environments (e.g., Spinks *et al.* 2003; Plummer and Mills 2008; Winchell and Gibbs 2016; Pittfield and Burger 2017). Urban systems are highly dynamic, creating continual changes to the surrounding environment. Knowledge of turtle resource requirements in response to external anthropogenic pressures is necessary as these requirements can vary temporally and spatially. Biologically relevant time periods and multiple spatial scales therefore need to be considered (Johnson 1980). Turtles are ectotherms, so their movement and habitat use are dictated by their thermal, metabolic, and reproductive needs. As such, their active season can be divided into three relevant time periods (emergence, nesting, and post-nesting), to better understand habitat selection and space use variation based on different phases of the seasonal cycle (Litzgus and Mousseau 2004; Rasmussen and Litzgus 2010). Knowledge of the core habitats and space required throughout the three phases of the active season is required to manage turtle habitat in urban systems.

Suitable overwintering habitat for adult turtles is a critical factor for northern populations over the long-term. At the extreme, turtles can spend four to six months under the ice, meaning that nearly half of their

lifetime is spent in overwintering habitat (Ultsch 2006; Jackson and Ultsch 2010). Overwintering habitats are chosen in the fall, and must be adequate to ensure survival until the ice recedes in the spring. A thermally stable aquatic habitat enables reduced metabolism; however, overwintering locations can prove to be physiologically stressful or lethal by exposing individuals to severe risks such as freezing, predation, anoxia, and metabolic acidosis (Ultsch 2006). In urban environments, the risk of overwintering site selection can increase because water levels are often artificially controlled. Water level reduction during the winter can result in mortality (Bodie and Semlitsch 2000). To effectively manage populations, we need a thorough understanding of habitat requirements not only during the active season, but also during the winter. Within Canada, most studies focus on populations inhabiting relatively pristine environments (e.g., Edge *et al.* 2009; Rasmussen and Litzgus 2010; Millar and Blouin-Demers 2011; Paterson *et al.* 2012). Few studies have examined overwintering habitat use in highly urban areas at northern latitudes.

Painted Turtles (*Chrysemys picta*) are one of the most widely distributed freshwater turtles in North America, reaching their northern limit throughout southern Canada. Painted Turtles typically inhabit shallow ponds, lakes, and slow-moving creek and river systems (Ernst and Lovich 2009; COSEWIC 2017). They are habitat generalists, able to adapt to their surrounding environment (Browne and Hecnar 2007) and are fairly tolerant of polluted waters (Ernst and Lovich 2009). Due to their wide range, and typically large population sizes in comparison to other freshwater turtles, Painted Turtles have become one of the most studied freshwater turtles in North America (Ernst and Lovich 2009; Lovich and Ennen 2013). Within Canada, many studies focus on Midland Painted Turtle (*C. p. marginata*) and examine aspects of their ecology and life history (e.g., Taylor and Nol 1989; Edwards and Blouin-Demers 2007; Rollinson and Brooks 2007; Carrière *et al.* 2008; Rollinson *et al.* 2008). Western Painted Turtle (*C. p. bellii*) has received little attention in regards to habitat and space use (e.g., MacCulloch and Secoy 1983a; St. Clair and Gregory 1990; Basaraba 2014), and therefore habitat requirements are derived from studies on the other subspecies (COSEWIC 2017). Western Painted Turtles attain larger body sizes, and reach higher latitudes than the other subspecies (Ernst and Lovich 2009), therefore their habitat and space use may differ from the smaller subspecies.

Here we examine year-round habitat selection and space use by an urban population of Western Painted Turtles in Regina, Saskatchewan. This population is in a major urban centre near the northern range limit for all turtle species on the Great Plains. Little is known about Western Painted Turtle habitat selection and space use in the Saskatchewan prairie environment where populations face climatic and anthropogenic extremes.

We hypothesized that turtle movements and home range sizes of males and females would vary across the active season based upon the reproductive-strategies hypothesis (Morreale *et al.* 1984). Correspondingly, we predicted that males would make the largest movements during emergence to find mates, and females would make the largest movements during nesting to find suitable nesting habitat. For habitat selection, we hypothesized that certain habitat features are necessary for turtle survival and reproduction in an urban environment. We predicted that turtles would select for particular habitats that facilitate foraging, thermoregulation, mating, and nesting. We predicted that turtles would select overwintering sites with deeper water, higher temperature, and more dissolved oxygen, compared to those available.

Study Area

Our study occurred in the City of Regina, Saskatchewan (50.417°N, 104.583°W), the provincial capital with over 214 000 residents (Statistics Canada 2017). The regional climate is characterized by short, warm summers and long, cold winters, an average of 115 frost-free days, and average daily maximum temperatures of 25.8°C (extreme: 43°C) in July and average daily minimum temperatures of -20.1°C (extreme: -50°C) in January (Environment Canada 2010). The harsh climate on the northern Great Plains results in only a small number of turtle species. In Saskatchewan, Snapping Turtle (*Chelydra serpentina*) and Western Painted Turtle reach the northern limit of their ranges; however, Western Painted Turtles are more widespread with populations throughout much of southern Saskatchewan.

Our study site was in the Wascana Creek watershed that begins southeast of Regina and flows west before entering the Qu'Appelle River. The study area was approximately 1000 ha, and consisted of two major habitat areas: a human-made lake (between Albert St. and Broad St.) and marsh (between Broad St. and Ring Rd.), and a creek flowing into the marsh on the east and flowing out of the lake on the west (Figure 1). The depth of the lake was artificially increased twice by draining and dredging in 1931 (average depth 2 m) and again during the winter of 2003–2004 (average depth 8 m) to improve water quality (Hughes 2005). The area surrounding the study site is primarily large green spaces such as urban parks and golf courses, as well as residential and commercial development; four major roads cross the study area. Most of the surrounding vegetation was originally planted in the early 1900s (Hughes 2005), with the current terrestrial shoreline dominated by large willow trees (*Salix* spp.) and emergent aquatic vegetation, largely consisting of Broad-leaved Cattail (*Typha latifolia* L.).

We defined two main habitat areas for turtles within the study site, marsh (which included the lake) and creek, separated by a large-scale water control dam under the Albert Street bridge (Figure 1) that appeared to be a complete barrier to turtle movement (K.A.M.

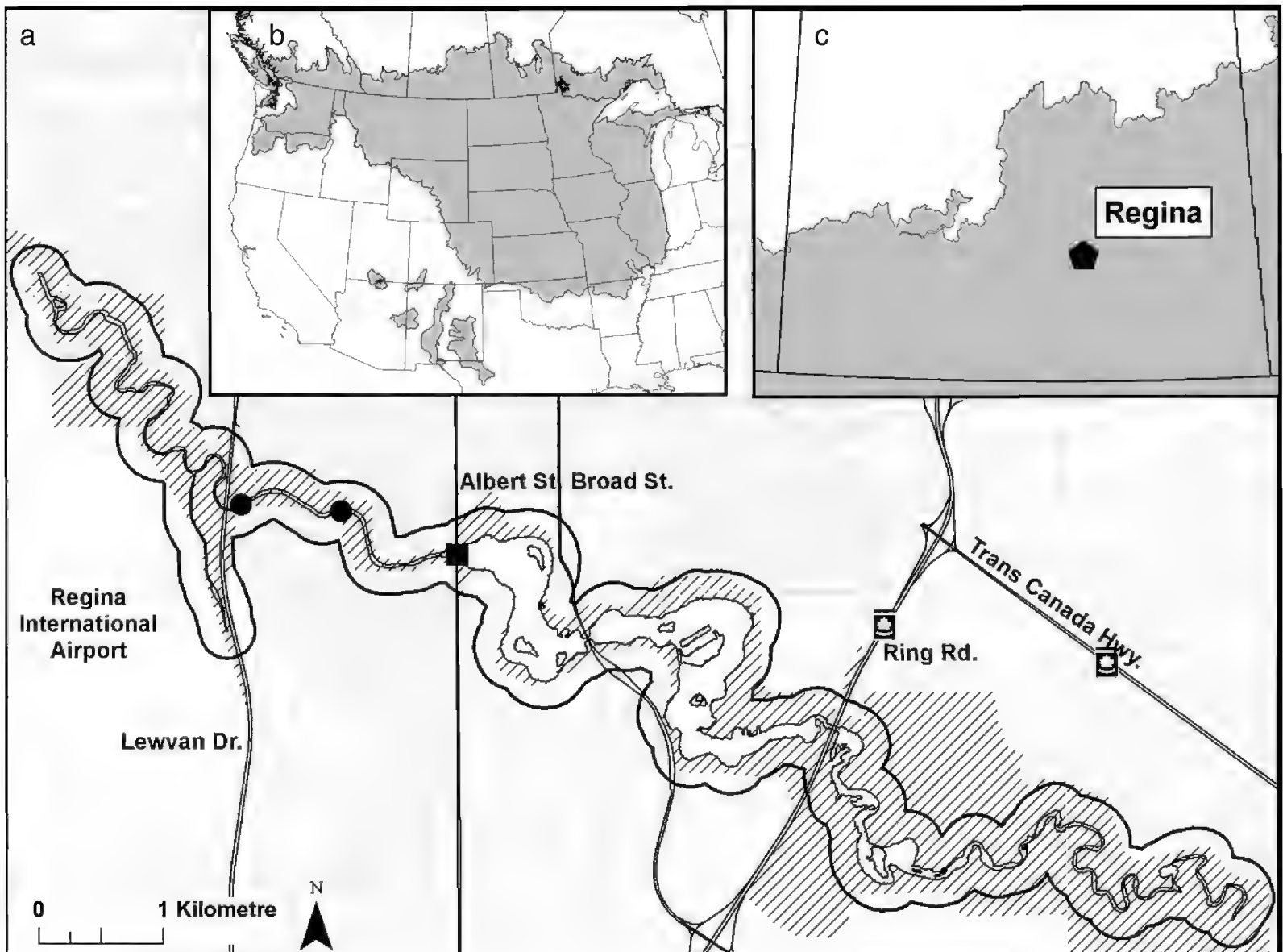


FIGURE 1. a. Study site in Regina, Saskatchewan showing the overall study area (1000 ha; black outline) indicating the barrier between the creek (West) and marsh/lake (East) habitat areas at Albert St. (square) and the two water control dams (circle) within the creek habitat. Hatched area indicates urban parkland. Insets display b. the North American range of Western Painted Turtle (*Chrysemys picta bellii*); and c. the location of the study area within Saskatchewan.

unpubl. data). Turtles caught west of the Albert Street bridge were deemed to be in creek habitat, and those caught east of the bridge were deemed to be in marsh habitat. The available habitat associated with the marsh and lake (water, shoreline, and 200 m urban buffer zone) was ~677 ha and ~270 m wide. The marsh area is designated a Federal Migratory Bird Sanctuary, and is not open to the public but the lake is open to recreational users, primarily canoes and kayaks. The creek habitat was ~325 ha and ~25 m wide with two water control dams. Few recreationists use the aquatic habitat but the surrounding parkland is used extensively.

Methods

Turtle capture and tracking

We captured turtles using a combination of hand capture, dip nets, and hoop traps baited with sardines, from April to September 2015 and 2016. Each individual was given a unique notch code that was filed into the marginal scutes of their carapace (Cagle 1939). Sex was determined using secondary sex characteristics (e.g., foreclaw length, pre-cloacal tail length, body size; Ernst and Lovich 2009). Individuals that did not display sec-

ondary sex characteristics were classified as sub-adults or juveniles (<115 cm carapace length). Body measurements were recorded, including body size (mid-line carapace length ± 1 mm), and mass (± 1 g). We attached radio transmitters (RI-2B, 14 g [$n = 25$] and 6 g [$n = 4$]; Holohil Systems Ltd., Ontario, Canada) to the rear marginal scutes using epoxy putty (Waterweld Epoxy Putty; J-B Weld, Texas, USA). The total mass of the unit (transmitter + epoxy) was <15 g and represented <5% of turtle body mass. In 2015 and 2016, 23 turtles (marsh: 12 females, four males; creek: four females, three males) and 29 turtles (marsh: 14 females, eight males; creek: four females, three males), respectively, were outfitted with radio transmitters. Twenty-two turtles (17 females, five males) were tracked in both the 2015 and 2016 field seasons. All turtles were released at the point of capture within 30 minutes.

We tracked turtles from a canoe in the open water season, and on foot (on the ice) during winter, using a portable receiver (R1000; Communications Specialists, Inc., Orange, California, USA) and hand-held three-element antenna. We relocated turtles throughout the year, separating the active season (May to September)

into three biologically relevant time periods during which we examined temporal variation (Table 1). During the active season, turtles were relocated roughly every other day. For each turtle relocation, the date, time, universal transverse mercator (UTM) coordinates, and the dominant broad- and fine-scale habitat types were recorded (Table 2). We recorded locations using a handheld global positioning system unit (Garmin eTrex 20; Garmin Ltd., Olathe, Kansas, USA) uploaded to ArcGIS version 10.3.1 (ESRI, Redlands, California, USA). Individuals monitored for less than three consecutive months during either the 2015 or 2016 active season, or with less than six relocations per activity period, were excluded from the yearly and seasonal analyses, respectively.

Population size estimate

To estimate total population size encompassing both the marsh and creek habitat areas across the 2015 and

2016 field seasons we used a modified version of the Lincoln-Petersen method (Lincoln 1930; Chapman 1951; Lancia *et al.* 2005). To meet assumptions of this approach, data on hatchlings were omitted from the calculation. Additionally, multiple methods of capture (hand capture and hoop traps) were used to reduce capture bias of individuals within the population.

Movement and home range size

We calculated distance moved using the *movement.pathmetrics* function in Geospatial Modelling Environment version 0.7.4.0 (GME; Beyer 2015) which allowed us to estimate step length measurements between successive relocations for each individual during the active season. The step length measurements were divided by the number of days between relocations to provide a relative minimum daily distance moved (DDM) for each tracked individual (Rasmussen and Litzgus 2010). During winter 2017, we examined

TABLE 1. Date ranges and descriptions for the four biologically relevant seasons used to describe home-range size and assess habitat selection of Western Painted Turtles (*Chrysemys picta bellii*) in Regina, Saskatchewan during 2015 and 2016.

Season	Year	No. turtles tracked	Relocation frequency (days ± SE)	Duration	Description
Emergence	2015	11	2 ± 0	11 May–28 May	Emergence from overwintering sites until the first gravid female was found (determined by palpation of the rear leg pocket)
	2016	28	4 ± 0	9 April–19 May	
Nesting	2015	22	2 ± 0	29 May–8 July	Continues until females are no longer found gravid
	2016	28	2 ± 0	20 May–5 July	
Post-nesting	2015	23	3 ± 0	9 July–3 September	Following nesting until return to overwintering areas
	2016	23	3 ± 0	6 July–10 September	
Fall (F)/ Winter (W)	2015	18	F: 7 ± 0 W: 30 ± 0	4 September–8 April	Movements within overwintering sites
	2016	15	F: 14 ± 0 W: 30 ± 0	10 September–7 April	

TABLE 2. Definitions for large-scale and fine-scale habitat features used in the compositional analysis of Western Painted Turtle (*Chrysemys picta bellii*) habitat in Regina, Saskatchewan. Broad-scale habitat was examined at second-order habitat selection, and fine scale habitat was examined at third-order habitat selection (Johnson 1980). Note: M = marsh, C = creek.

Feature type	Habitat type	Description	Percent of habitat (%)
Broad-scale	Shoreline	15 m zone on either side of the delineated shoreline	15.0
	Urban/Parkland	200 m zone around the study area (Steen <i>et al.</i> 2012; COSEWIC 2017)	74.0
	Open water	Open water remaining between shoreline buffer areas	17.0
Fine-scale	Barrier	Human-made vertical barrier preventing shoreline access for turtles	M: 6.0 C: 3.5
	Cattails	Shoreline dominated by cattail vegetation	M: 60.3 C: 28.6
	No vegetation	Shoreline consists of open beach area; either cobblestones, soil, or sand	M: 7.4 C: 0.5
	Shrubs	Shoreline dominated by short, dense shrub vegetation; no visible bank	M: 11.0 C: 31.5
	Trees	Shoreline dominated by large overhanging trees (typically willow); bank always visible	M: 15.3 C: 35.9

turtle movement under the ice by measuring the straight-line distance between successive relocations in ArcGIS. We deployed a reference transmitter attached to a rock in the overwintering area to use as a control to confirm turtle movement.

We determined the home range of individuals by calculating the 100% minimum convex polygon (MCP) using the *genmcp* function in GME, which provides the smallest possible convex polygon that encompasses all relocations for a particular individual or group of individuals (Row and Blouin-Demers 2006). We chose MCPs over other home range metrics (e.g., kernel density) because they eliminate the effect of autocorrelation, reduce the number of arbitrary choices required in the analysis (e.g., smoothing factor), and encompass areas that may be used as movement corridors and, thus, are excluded when using kernel density estimates (Row and Blouin-Demers 2006; Rasmussen and Litzgus 2010; Markle and Chow-Fraser 2014).

All active season movement and home range data were analyzed to determine effects of season, sex, habitat area, and year on movement rates and home range size using two separate generalized linear mixed models (GLMM; Gamma distribution). The fixed effects included season, sex, habitat area, and year. The random effect was turtle ID to account for repeated measures of each individual. A χ^2 test was completed to examine the effect of the interaction between season and sex. Analyses were conducted using the *lme4* package (Bates *et al.* 2015) in R version 3.3.1 (R Core Team 2016) and assumed a significance level of $P < 0.05$. We report the mean \pm SE where appropriate.

Habitat selection

We examined habitat selection using compositional analysis at two spatial scales representing two categories in Johnson's (1980) hierarchy to determine whether the turtles select particular habitats disproportionately compared to what was available (Aebischer *et al.* 1993): broad-scale representing second-order selection and fine-scale representing third-order selection (Table 2). Second-order habitat selection was assessed by comparing the proportion of relocations of each individual turtle to the proportion of broad-scale habitat features available within the MCP for the entire population. Third-order habitat selection was assessed by comparing the proportion of relocations of each individual turtle within each section of the active season to the proportion of habitat features available within individual active season MCPs. Compositional analyses were completed using the *compana* function in the *adehabitatHS* package in R (Calenge 2006). In cases where habitat types were available but not used, we replaced the zero value with a value one order of magnitude smaller than the smallest non-zero number in the dataset (Aebischer *et al.* 1993).

Overwintering site selection

During the winter of 2015–2016 and 2016–2017, we determined overwintering locations for 19 turtles (15 marsh, four creek), and 18 turtles (14 marsh, four creek), respectively. Due to ice safety concerns, only turtles located within the marsh habitat between Broad Street and Ring Road were monitored throughout the winter months. We measured environmental variables at used and available overwintering sites from January to March by drilling holes through the ice using an auger. We chose representative used sites that were centrally located near groups of turtles with transmitters, and at least 15 m apart from other sites used for overwintering. We designated representative sites used in this way to avoid drilling through the ice directly above each turtle, potentially causing disturbance. At each site, a hole was augured into the ice and environmental variables were recorded including distance from shore (m), water depth (cm), ice thickness (cm), water temperature ($^{\circ}\text{C}$), and dissolved oxygen level (mg/L). Both water temperature and dissolved oxygen level were measured using a YSI probe (YSI Pro Plus; YSI Inc., Yellow Springs, Ohio, USA). To examine differences in the sites used for overwintering compared to areas within the known overwintering habitat, we sampled available sites 10 m in each cardinal direction from the selected sites, as well as 30 m and 50 m west from the selected sites. To examine why the turtles selected their overwintering location versus another location available to them in the marsh habitat, we compared the sites used for overwintering to 12 randomly selected available sites. The randomly selected available sites were generated in ArcGIS using the *Random Points* function in the Data Management Toolbox.

To examine overwintering habitat selection, two separate GLMMs were constructed to examine the relationship between measured environmental variables and several fixed variables: within the known overwintering habitat and across the marsh habitat. Fixed variables included sample month, sample year, and location type (used or available). Environmental variables were recorded monthly during the winter of 2016 and 2017, so site ID was used as a random effect to account for repeated measures. This approach enabled testing the hypothesis that environmental variables differed between used and available overwintering sites. Analyses were conducted using the *lme4* package in R assuming a significance of $P < 0.05$. We report the mean \pm SE where appropriate.

Results

Population size assessment

We captured 85 turtles (26 males, 43 females, eight juveniles, and eight neonates) and recaptured 47 turtles (16 males, 31 females) in 2016 within the creek and marsh habitat. The majority of the individuals captured (88%) were from the marsh habitat, with only 10 individuals (six females, four males) found in the creek

habitat. Most individuals were sexually mature adults with carapace length over 150 mm. Using the Lincoln-Petersen method, we estimated the total population size to be 82 individuals (± 8 ; 95% CI), resulting in a density of 0.3 turtles/ha within available shoreline and open water habitat with the marsh and the creek areas combined.

Movements and home range

Across the 2015 and 2016 field seasons, the average daily distance moved was 96 ± 8 m and 172 ± 6 m for the creek and marsh areas, respectively. The average distance that female turtles moved into upland habitat was 36 ± 10 m. The upland movements primarily occurred during nesting season. The maximum distance travelled into upland habitat was a female who moved 265 m in late July to reach a water retention pond near a golf course where she remained until fall. One male moved into upland habitat (200 m), but returned to the aquatic habitat by the next relocation. It is unclear what caused the upland movement; however, based on relocation frequency he may have spent a maximum of three days outside the creek habitat. Daily movement rates did not differ between the 2015 (162 ± 7 m) and 2016 (153 ± 7 m) active seasons ($t_1 = 0.14$, $P = 0.9$). There was no significant difference in the DDM between males and females ($t_1 = 1.7$, $P = 0.09$; Figure 2a). Marsh turtles moved longer distances compared to creek turtles ($t_1 = 11.5$, $P < 0.01$), with mean marsh turtle movements being two times longer compared to those in the creek (Figure 2b). Turtles moved longer distances during nesting ($t_2 = 7.6$, $P < 0.01$) and post-

nesting ($t_2 = 4.6$, $P < 0.01$) seasons compared to during emergence (Figure 2c); however, there was no significant interaction between sex and season on DDM ($\chi^2_2 = 4.1$, $P = 0.1$; Figure 2d). During winter 2017, under ice movements were recorded. In February, turtles were found 4 ± 0.8 m (control = 0 m) from their January location. In March, turtles were found 20 ± 5 m (control = 1 m) from their February location.

Home ranges did not differ between 2015 and 2016 ($t_1 = 1.2$, $P = 0.2$). There was no significant difference between male and female home ranges ($t_1 = 0.35$, $P = 0.7$). The home ranges were significantly larger for the marsh turtles (59 ± 5 ha) than the creek turtles (19 ± 4 ha; $t_1 = 5.9$, $P < 0.01$). Across the active season, turtles had significantly larger home ranges during the nesting ($t_2 = 5.7$, $P < 0.01$) and post-nesting seasons ($t_2 = 7.2$, $P < 0.01$) compared to emergence, corresponding with increased DDM values. The interaction between sex and season did not affect turtle home range size ($\chi^2_2 = 2.8$, $P = 0.3$).

Active season habitat selection

Second-order habitat use was significantly non-random (Wilk's $\lambda_2 = 0.06$, $P = 0.002$). Shoreline habitat was used six times more than expected, accounting for 93% of the turtle relocations, and open water and urban/parkland were both used less than expected based on availability. At third-order, creek turtles used shoreline with no-vegetation 33–54 times more than expected based on availability during all three sections of the active season (Figure 3). Compositional analysis did not identify habitat use as significant (emergence: Wilk's

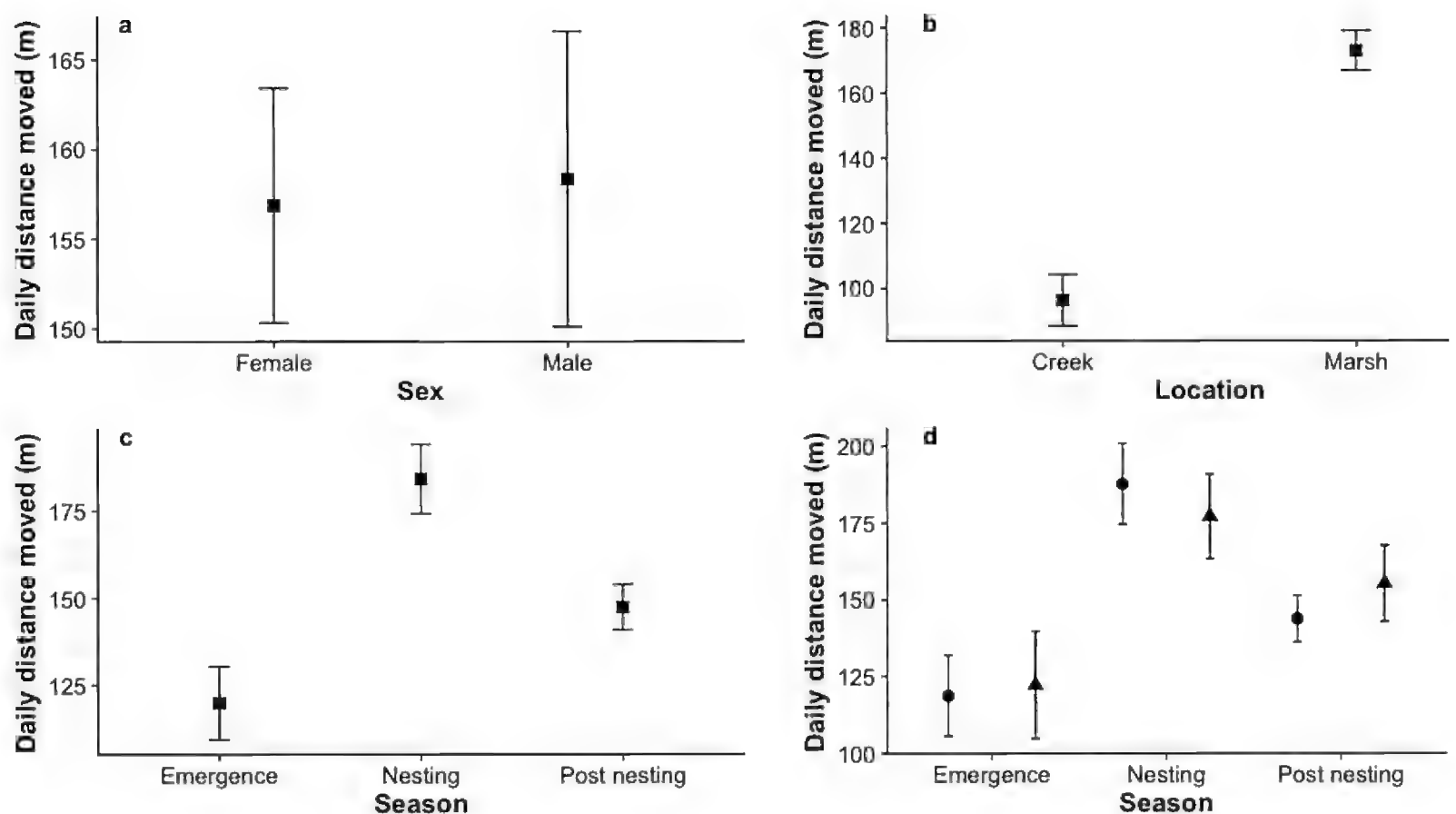


FIGURE 2. Mean (\pm SE) daily distance moved for Western Painted Turtles (*Chrysemys picta bellii*) in Regina, Saskatchewan showing variation between a. sex, b. location, c. season, and d. females (circle) and males (triangle) across the active season.

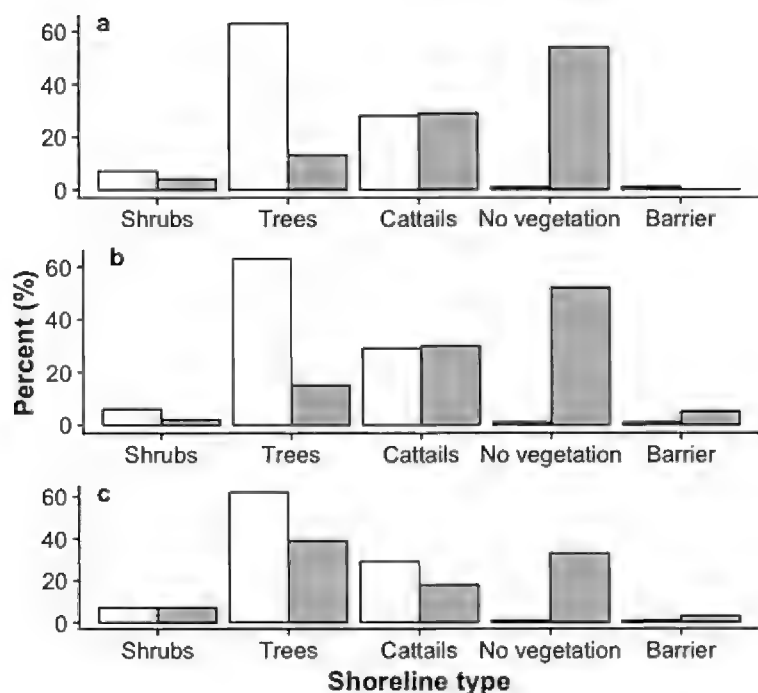


FIGURE 3. Proportion of used (grey) and available (white) shoreline habitat types within the creek habitat area during a. emergence, b. nesting, and c. post-nesting seasons.

$\lambda_4 = 0$, $P = 1$; nesting: Wilk's $\lambda_4 = 0.02$, $P = 0.09$; post-nesting: Wilk's $\lambda_4 = 0.1$, $P = 0.2$), which could be a result of a small sample size (Aebischer *et al.* 1993). In contrast, marsh turtles exhibited significant non-random habitat use across all three periods of the active season (emergence: Wilk's $\lambda_4 = 0.02$, $P = 0.002$; nesting: Wilk's $\lambda_4 = 0.14$, $P = 0.002$; post-nesting: Wilk's $\lambda_4 = 0.1$, $P = 0.002$), with shorelines consisting of trees, shrubs, and cattails being used more than expected, and no-vegetation and barrier shorelines being used less than expected based on availability. Treed shoreline accounted for on average 51% of the relocations within each period of the active season, and was selected for 1.3 times more than expected during emergence and two times more than expected during nesting and post-nesting based on availability. Within the emergence period, shrub shoreline accounted for 36% of the relocations and during both nesting and post-nesting periods, cattail shoreline accounted for 32% and 22% of relocations, respectively.

Overwintering site selection

During 2016 and 2017, the marsh habitat had approximately 142 and 136 days of ice cover, respectively. Turtles ($n = 13$) overwintered between a pair of islands along the east shore, 7 ± 0.5 m from the shoreline in 2016 and 9 ± 0.4 m from the shoreline in 2017. On average across the two years, the sites used for overwintering experienced dissolved oxygen levels of 3.8 ± 0.97 mg/L (minimum: 0.6 mg/L), water temperature of $1.6 \pm 0.22^\circ\text{C}$ (minimum: 0.1°C), and water depths of 148 ± 14 cm (minimum: 53 cm). Within the immediate overwintering habitat there were no significant differences in water temperature ($t_1 = -0.98$, $P = 0.3$), dissolved oxygen level ($t_1 = 0.74$, $P = 0.5$), or water depth ($t_1 = -1.4$, $P = 0.2$) between the sites used for overwintering and the randomly selected available

sites. All sites within the immediate overwintering area exhibited temporal variation. In 2017, the dissolved oxygen levels were significantly higher (4 ± 4 mg/L; $t_1 = 5.7$, $P < 0.01$), the water temperatures were significantly lower ($1.5 \pm 0.6^\circ\text{C}$; $t_1 = -11.3$, $P < 0.01$), and the water depths were significantly shallower (195 ± 82 cm; $t_1 = -1.4$, $P < 0.01$) compared to 2016. Across both years, the dissolved oxygen levels were significantly higher ($t_2 = 12.4$, $P < 0.01$), the water temperatures significantly higher ($t_2 = 11.8$, $P < 0.01$), and the water depth significantly lower ($t_2 = -3.5$, $P < 0.01$) in March compared to January and February.

Sites used for overwintering were significantly warmer ($t_1 = 2.4$, $P = 0.02$) and deeper ($t_1 = 2.3$, $P = 0.02$) than randomly selected available sites; but there was no significant difference in the dissolved oxygen levels ($t_1 = -0.34$, $P = 0.7$; Figure 4). Over the course of the winter, multiple available sites froze to the bottom (2016: $n = 3$; 2017: $n = 9$); however, sites used for overwintering did not freeze to the bottom. Water temperatures were significantly lower ($t_1 = -3.5$, $P < 0.01$), and water depths significantly shallower ($t_1 = -6.5$, $P < 0.01$) in 2017 compared to 2016. Across both years, dissolved oxygen levels were significantly higher in March ($t_2 = 4.1$, $P < 0.01$) compared to January and February, and water depths were significantly deeper in January ($t_2 = 3.7$, $P < 0.01$) compared to February and March.

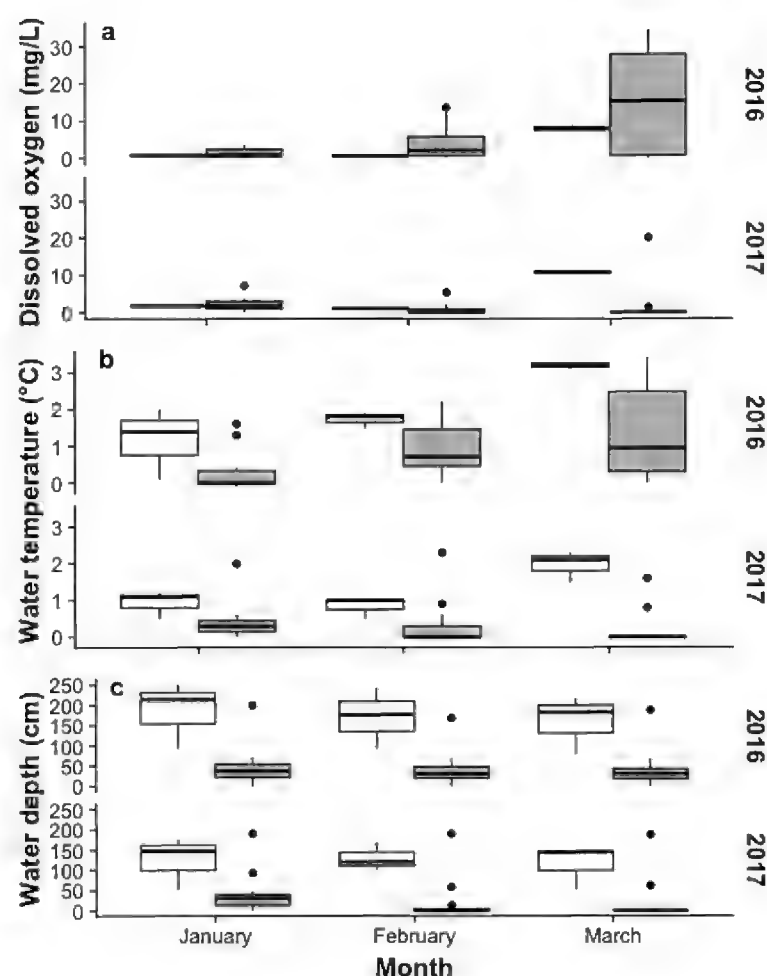


FIGURE 4. Boxplots of a. dissolved oxygen, b. water temperature, and c. water depth recorded at used (white; $n = 3$) and available (random: grey; $n = 12$) sites during the winter of 2016 and 2017. The median is depicted as the horizontal black line, boxes represent the 25th and 75th percentiles, whiskers depict the highest and lowest values, and the black circles represent outliers.

Discussion

Population size assessment

We estimated the population to be 82 (± 8) individuals, at a density of 0.3 turtles/ha, which was lower than typically recorded for this species. Painted Turtles are one of the most abundant freshwater turtle species within their range (Ernst and Lovich 2009), with some populations attaining sizes of over 3000 individuals (828 turtles/ha; Frazer *et al.* 1991). At the northern range limit in Canada, reported population sizes for Western Painted Turtles are sparse. However, a population inhabiting a water reservoir in Revelstoke, British Columbia was estimated to be approximately 242 individuals (2 turtles/ha; Basaraba 2014), and a population inhabiting the Qu'Appelle River north of Regina was estimated to be 167 individuals (11 turtles/ha; MacCulloch and Secoy 1983b). Both of these estimates are two- to three-times larger than the estimate for our study population, indicating that our study site has a lower population density than reported populations.

The majority of turtles captured during the study were sexually mature individuals over 150 mm carapace length. We captured few juveniles and subadults. Within the total study population, female turtles occurred more commonly than males by approximately a 2:1 ratio (43 females: 26 males). The high capture rate of sexually mature individuals may be the result of sampling bias, as juveniles are cryptic and difficult to capture in the traps we deployed, or an indication of low productivity and recruitment. An age shift towards adults has been previously observed in freshwater turtle populations that have been affected by anthropogenic changes (Garber and Burger 1995; Saumure and Bider 1998; Browne and Hecnar 2007). Over the two years, we only observed one successful nest (eight hatchlings), and many were found predated, mostly by Richardson's Ground Squirrels (*Urocitellus richardsonii*). This was the first assessment of population size for this study area, so temporal comparisons are not possible. However, the information gathered in the current study can be used as a baseline for future population monitoring.

Turtle movements and home range

Western Painted Turtles in this study did not conform to predictions about seasonal movements based upon the reproductive strategies hypothesis. We found that turtle movements and space use did not differ between sexes and that variation was more attributable to the season in which the movements occurred, with both sexes exhibiting decreased movement and space use during emergence in comparison to nesting and post-nesting phases of the active season. This pattern may reflect metabolic requirements as well as a response to environmental temperatures, as activity does not begin until water levels reach approximately 10°C (Ernst 1971). During emergence, Painted Turtles spend increased time basking allowing them to conserve energy, increase their body temperature following emergence,

and overcome acidosis experienced during overwintering (Congdon 1989; Edwards and Blouin-Demers 2007; Carrière *et al.* 2008; Millar and Blouin-Demers 2011). Freshwater turtles such as Spotted Turtle (*Clemmys guttata*; Litzgus and Mousseau 2004) and Blanding's Turtle (*Emydoidea blandingii*; Millar and Blouin-Demers 2011) communally aggregate following hibernation, which reduces the requirement of males to actively seek females throughout the habitat. Therefore, the mixed-sex basking aggregations observed in our study population could explain the limited movements of males in contrast to the reproductive strategies hypothesis. Movements and space use increased during nesting and post-nesting phases. In addition to coinciding with warmer seasonal temperatures, this increased activity is likely related to increased efforts in searching for desired nesting habitat, food resources, or potential mates.

Movements into upland habitat were only documented during the nesting season. In contrast to previous studies (e.g., McAuliffe 1978; Bowne 2008), we did not document turtles making large overland movements to reach alternate habitat, as the majority of relocations were confined to shoreline and open water. During the nesting season, females moved into upland habitat on average <50 m from the shoreline. However, despite this very limited upland movement, females still came into contact with roads. Three females (7% of captured females) were hit by vehicles, two of which were found to be gravid, a mortality rate which, if continued, exceeds a sustainable annual loss to our study population (Brooks *et al.* 1990; Congdon *et al.* 1993; Gibbs and Shriver 2002). One additional female was documented nesting in a gravel back alley roadway ~25 m from the creek, an area bordered by residential houses and small parkland. Steen *et al.* (2012) found that Painted Turtles typically nest within 200 m of the shoreline. However, the distance travelled decreases in disturbed habitat, with females opting to nest in close proximity to the shoreline (Baldwin *et al.* 2004; Foley *et al.* 2012), which is consistent with findings in our study.

The average home range size and daily distance moved for Western Painted Turtles in our study were typical for that of the species in other parts of its range. The average home range size for turtles in both the marsh and the creek habitat areas are comparable to those reported in British Columbia, Tennessee, Ohio, and Pennsylvania (Saba and Spotila 2003; Tran *et al.* 2007; Jaeger and Cobb 2012; Basaraba 2014). In contrast, our home range estimates are 4–12 times larger than that reported for the Qu'Appelle River population north of Regina (MacCulloch and Secoy 1983a). This comparison should be interpreted with caution given the different survey methods used in the two studies. Marsh turtles had significantly larger movement rates and space use in comparison to the creek turtles. Previous studies have found a link between animal space use and the amount of habitat available (Schubauer *et al.*

1990; Plummer *et al.* 1997; Jaeger and Cobb 2012). Animals with less available habitat by necessity have smaller home ranges compared to those with more available habitat. Therefore, the observed variation in our system may not be attributed to activity level differences, but rather the space available to the individuals within them.

Active season habitat selection

Turtles across our study area selected strongly for shoreline areas; however, the features of the shoreline selected varied between marsh and creek. For example, at the level of third order habitat selection, turtles in the marsh were found to select for treed shorelines, whereas turtles in the creek preferred shorelines with no vegetation. The habitat preferences turtles exhibited were consistent with studies on other Painted Turtle subspecies; they are commonly associated with shoreline habitats (Rowe and Dalgarn 2010) and they are most commonly found on shorelines with partial cover and suitable basking areas (Pittfield and Burger 2017). In contrast to other freshwater turtles (e.g., Litzgus and Mousseau 2004; Markle and Chow-Fraser 2014), Western Painted Turtles did not shift habitat selection throughout the active season. Within the Regina urban environment, turtles may prefer to use habitat with increased protection from human disturbance, while at the same time meeting their needs as ectotherms (i.e., basking). Additionally, suitable habitat may be limited in our system, as most natural shoreline features are represented in low proportions.

Overwintering site selection

Individuals displayed high site fidelity to one overwintering area, indicating that this overwintering location may be particularly important for our study population. The area used for overwintering was the single protected area that was not drained for the large-scale dredging event through the winter of 2004. In the winters of 2015–2016 and 2016–2017, all monitored turtles returned to the same 90 m section of shoreline, after being dispersed throughout the habitat during the active season. The high site fidelity to overwintering sites and the aggregation of turtles is consistent to what is observed in Spotted Turtles (Rasmussen and Litzgus 2010) and Snapping Turtles (Brown and Brooks 1994) at their northern range limits, where suitable overwintering habitat may be limited. We found that turtles selected sites close to shore, which would allow them to be exposed to warmer water earlier in the spring than deeper areas (Ultsch 1989). Overwintering movements were negligible through the winter, but by March some turtles began to move, perhaps to seek areas with increased dissolved oxygen levels produced by incoming melt water (Ultsch 1989).

The ranges of environmental conditions at the sites used for overwintering were similar to those documented for Western Painted Turtles in British Columbia (St.

Clair and Gregory 1990; Wood and Hawkes 2014) as well as for other subspecies across the range (Crawford 1991; Crocker *et al.* 2000; Rollinson *et al.* 2008). Contrary to what we expected, there was no support for the hypothesis that turtles selected sites based on dissolved oxygen levels in the water, as all used and available sites became hypoxic. However, they did select sites that were warmer and deeper compared to those randomly available to them. Lab data suggest that Painted Turtles can survive 118–150 days in anoxic conditions at 3°C (Reese *et al.* 2004; Jackson and Ultsch 2010), with Western Painted Turtles from northern populations better able to cope with the physiological effects of anoxia by accumulating less lactate than southern conspecifics and other subspecies (Reese *et al.* 2004). Therefore, similar to what was found in Blanding's Turtles in Ontario (Edge *et al.* 2009), choosing an overwintering location that will not freeze because of increased water depth and temperature may outweigh the risk of metabolic acidosis due to anoxia.

Management implications

Our data provide baseline information on population demographics and identify space use and habitat requirements of an urban population of Western Painted Turtles near the northern limit of the species range. The data we obtained from our study can serve as a baseline to document temporal changes in population size and habitat use. Through our study, we identified that overwintering habitat is critical to the persistence of this urban population. Turtles in our study population were found to move towards overwintering habitat by the beginning of September. A minimum of 2 m of water is required within 7–10 m of the shoreline in the core overwintering habitat, to ensure viable water temperatures over the winter. To ensure winter survival, water levels should not be dropped by more than 0.5 m through the winter, as this would cause overwintering sites to be compromised. Draining of Wascana Creek should be avoided. However, if depth management of Wascana Creek via dredging over the winter is found to be necessary, the core overwintering habitat should be protected so that it does not freeze solid or become drained of water.

The aquatic and terrestrial areas of the park should be managed to ensure a mosaic of shoreline habitats, which includes overhanging trees and submerged logs, to provide a protective buffer between the turtles and recreationists, and provide suitable basking areas to meet their thermal requirements. Shorelines dominated by concrete barriers and areas without vegetation cover should not be created as they will restrict shoreline access; however, they may be beneficial in high-risk areas (i.e., roadsides) to minimize risk of mortality. Finally, the majority of the population inhabits the eastern portion of the marsh, the Federal Migratory Bird Sanctuary. Public access to this section should continue to be restricted to minimize human disturbance.

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Note

Spiny Softshell (*Apalone spinifera*) turtles exhibit scarring consistent with attempted lamprey bites

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Abstract

We captured 46 Spiny Softshells (*Apalone spinifera*) during a mark–recapture study on Lake Erie (2012–2015). Six (13%) exhibited circular scars consistent with the bites of small parasitic lampreys. Two species of parasitic lampreys occur in Lake Erie: the invasive Sea Lamprey (*Petromyzon marinus*) and the native Silver Lamprey (*Ichthyostomyzon unicuspis*). The scars showed only the marks of the putative teeth surrounding the suctional mouth, preventing identification based on the position of the supraoral teeth and suggesting that lampreys are rapidly dislodged from the turtles. To our knowledge, this is the first evidence of lampreys biting freshwater turtles.

Key words: Spiny Softshell turtle; *Apalone spinifera*; *Ichthyostomyzon unicuspis*; parasitic lamprey; *Petromyzon marinus*; Sea Lamprey; Silver Lamprey; turtle; Lake Erie

Sea Lamprey (*Petromyzon marinus*) was inadvertently introduced into the Great Lakes in 1921, where it has had a devastating impact on the Great Lakes fisheries of Canada and the United States (Shetter 1949; Lawrie 1970). Sea Lamprey wounds are most commonly recorded on Lake Trout (*Salvelinus namaycush*; Shetter 1949; Lawrie 1970; Christie and Goddard 2003); however, a range of other teleosts also exhibit lamprey wounds (Shetter 1949). Sea Lampreys primarily feed on the blood and muscle tissue of the host species (Farmer 1980). Scars from these encounters are oval and occasionally show circular rings of tooth marks, which confirm that they were made by Sea Lampreys (Pike 1951). Parasite–prey dynamics and interactions between teleosts and lampreys in the Great Lakes have been well documented (Sullivan *et al.* 2003; Stapanian and Madenjian 2007), but little is known about other prey and feeding strategies.

From 2012 to 2015, we captured, marked, and released 46 Spiny Softshell (*Apalone spinifera*) turtles (45 females, one male; 64 captures in total) in and around Rondeau Provincial Park, on the north shore of Lake Erie, Chatham-Kent County, Ontario, Canada (42.286634°N, 81.896193°W). Spiny Softshells often exhibit a variety of marks on the carapace consistent with abrasion or infection, although we have not quantified the frequency of these during our surveys.

In 2014, we observed that five adult females and one male (13% of all individuals captured) exhibited different, distinctive scarring on their carapace that was potentially consistent with lamprey (Family Petromyzontidae) bites. Unlike typical small lesions from abra-

sions or infections, these scars consisted of a circle of regularly spaced punctures into the epidermis, approximately 1 cm in diameter, hypothetically consistent with the ring of teeth surrounding a lamprey's suctional mouth (Figure 1). The depressions formed by these punctures caused the undamaged skin in the centre of the ring to appear slightly raised (~5 mm) above the surface of the surrounding carapace. Lamprey-like scarring on Spiny Softshells was observed only on the carapace, and, in

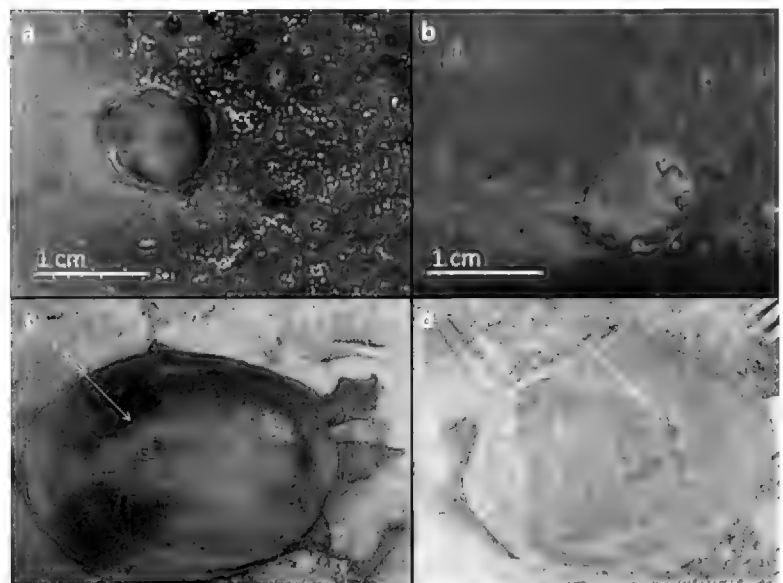


FIGURE 1. Two examples of observed scarring, potentially consistent with lamprey bites, on the carapace of female Spiny Softshells (*Apalone spinifera*) captured at Rondeau Provincial Park, Chatham-Kent County, Ontario. Panels a and b show the characteristic ring of punctures surrounding unbroken epidermis, which differs from the lesions associated with infections or abrasions. Panels c and d show the locations of these marks (white arrows) on the carapaces of two turtles. Photos: A.K. Whitear (a, c) and Juliana Skuza (b, d).

all instances, the scarring was located in the central (bony) portion of the carapace. The scars appeared fully healed, and, in one scarred turtle that was originally captured in 2014 and then recaptured in 2015, the scar retained its appearance between captures. All scarred turtles were mature (mean female carapace length = 439 mm, range = 385–473 mm; male carapace length = 184 mm).

The introduced *P. marinus* shares Lake Erie with a native parasitic lamprey, Silver Lamprey (*Ichthyomyzon unicuspis*). The Great Lakes–St. Lawrence population of *I. unicuspis* was assessed as a species of Special Concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2011). Bites of *P. marinus* and *I. unicuspis* may be distinguished based on the pattern of the supraorbital teeth (Pike 1951; Scott and Crossman 1998). However, the observed scars only contained marks consistent with the teeth surrounding the suctorial mouth. None included potential scarring from the supraoral teeth or rasping tongue. This is unsurprising, as softshell turtles have a strong bite. We suspect that any lamprey trying to attach to the carapace of a Spiny Softshell would be rapidly discouraged by the turtle's strong jaws, if it attached at a point that the turtle could reach. Alternatively, it may be difficult for lamprey to fasten securely onto the bony, smooth carapace of a Spiny Softshell.

To the best of our knowledge, this is the first reported evidence of lamprey attachment on freshwater turtles in Canada. It would be ideal to confirm our hypothesis with observations of lampreys attaching or attached to turtles, but this is unlikely in the wild. Still, we are unable to find a convincing competing hypothesis for the observed scarring. All Spiny Softshells with potential lamprey scars behaved normally, and the sites of the scars appeared to be fully healed. Any open wound can provide an avenue for infection, but turtles at our study site often sustain minor or even surprisingly severe injuries that do not impact their survival. If lampreys are indeed the cause of the observed marks, we consider it unlikely that this interaction would cause mortality or even have a significant sublethal impact on Spiny Softshells.

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Depredation of gravid freshwater turtles by Raccoons (*Procyon lotor*)

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Abstract

During summer 2017, we found 19 dead or fatally wounded adult female turtles belonging to three at-risk species at a nesting site on the north shore of Lake Erie, Ontario. Individuals were found flipped onto their carapace, had similar holes in their body cavities, and were eviscerated. Their eggs had also been consumed. Although turtle nest depredation by Raccoons (*Procyon lotor*) is common, it is unusual for them to target large numbers of gravid turtles within a season. Depredated species included Snapping Turtle (*Chelydra serpentina*), Northern Map Turtle (*Graptemys geographica*), and Blanding's Turtle (*Emydoidea blandingii*). Our observation represents a spike in additive mortality for these populations, which could have long-term demographic consequences.

Key words: Additive mortality; depredation; predator; Raccoon; *Procyon lotor*; Blanding's Turtle; *Emydoidea blandingii*; Northern Map Turtle; *Graptemys geographica*; Snapping Turtle; *Chelydra serpentina*; Ontario

Introduction

Freshwater turtles typically exhibit high life expectancy and mortality rates that are inversely related to age (Iverson 1991). High depredation of eggs and hatchlings in the wild results in low recruitment of early life stages (Iverson 1991). Some North American freshwater turtle populations experience nest predation rates approaching 100% (63%: Congdon *et al.* 1983; 70%: Congdon *et al.* 1987; 84.2%: Burke *et al.* 1998). Elasticity (the proportional contribution of stage-specific demographic parameters to population growth) is low for turtle hatchlings relative to mature females. Populations with high adult survivorship can tolerate relatively high nest depredation as long as some recruitment is still occurring. In contrast, removing even a few mature individuals from a population may result in a disproportionately large decrease in population growth (Heppell 1998). Thus, additive mortality of adults can limit the growth of turtle populations, particularly those that are already in decline (Brooks *et al.* 1991; Stacy *et al.* 2014).

In North America, mammalian mesopredators are frequently observed depredating turtle nests. Common nest predators include Raccoon (*Procyon lotor*), Fisher (*Martes pennanti*), Gray Fox (*Urocyon cinereoargenteus*), Red Fox (*Vulpes vulpes*), River Otter (*Lutra canadensis*), American Mink (*Neovison vison*), Striped Skunk (*Mephitis mephitis*), Virginia Opossum (*Didelphis virginiana*), Eastern Wolf (*Canis lycaon*), and Coyote (*Canis latrans*; Wilhoft *et al.* 1979; Marchand *et al.* 2002; Geller 2012; Riley and Litzgus 2014). Adult turtles are more rarely targetted by predators because many species can retract into their shells for protection. Snapping Turtle (*Chelydra serpentina*) cannot fully retract,

but instead displays intimidating snapping behaviour when threatened (Ernst and Lovich 2009). Nevertheless, predation of adult turtles does occur (Brooks *et al.* 1991; Baxter-Gilbert *et al.* 2013).

Erickson and Scudder (1947) suspected Raccoons as the cause of death of 26 nesting Yellow-bellied Sliders (*Trachemys scripta scripta*) and four Eastern Mud Turtles (*Kinosternon subrubrum*). They reported that these turtles shared similar injuries to the neck, intestines, and oviducts, with some carcasses adjacent to egg shells and Raccoon tracks. Similar injuries were reported on 28 depredated adult Diamond-backed Terrapins (*Malaclemys terrapin*) found during the nesting season in Gateway National Recreation Area, New York, in 1998–1999 (Feinberg and Burke 2003) and on 24 Diamond-backed Terrapins found in Merritt Island, Florida, in 1977–1978 (Seigel 1980). These authors also considered Raccoons as the most likely predator.

In 2004–2005, 35 Wood Turtle (*Glyptemys insculpta*) deaths at a site in Quebec were attributed to depredation by Raccoons (Pouliot *et al.* 2013). In some cases, Raccoons were observed attacking nesting Wood Turtles, and some dead individuals had sustained injuries that suggested they were being targetted for the unlaidd eggs in their oviducts (Pouliot *et al.* 2013). Mustelids, such as American Mink and River Otter, may also depredate hibernating turtles during the winter (Brooks *et al.* 1991; Lanszki *et al.* 2006), when cold temperatures and potential hypoxia during hibernation reduce the turtle's ability to move quickly (Ultsch 1989). River Otters were recently implicated in a mass mortality of Blanding's Turtles (*Emydoidea blandingii*) on Manitoulin Island, Ontario, which increased the likelihood of extirpation for that population (Gasbarrini 2016).

Methods

In summer 2017, we conducted turtle nesting surveys at Rondeau Provincial Park (42.2808°N, 81.8525°W; Chatham-Kent County, Ontario, Canada) during an ongoing turtle conservation and research program. We monitored a nesting site (3.5 km long) daily from 5 June to 30 July 2017, with surveys typically running from 0900 to 1900. During this time, we observed semi-regular depredation of gravid or nesting females. In each case, we recorded specific injuries, measured the turtle's size (curved carapace length), and noted any evidence identifying potential predators. Following our first few observations of depredation, we also deployed Hyperfire trail cameras (Reconyx, Holmen, Wisconsin, USA) along the nesting site, in an effort to document potential predators.

Results

We observed 19 cases of depredation on gravid or post-nesting turtles: 10 Snapping Turtles, eight Northern Map Turtles (*Graptemys geographica*), and one Blanding's Turtle. All were mature females (mean curved carapace length \pm SD for Snapping Turtles:

242.89 \pm 13.50 mm; Northern Map Turtles: 313.13 \pm 16.13 mm; Blanding's Turtle: 218 mm). The pattern of attacks was consistent among incidents. Each turtle was found flipped onto its carapace and with similar wounds (Figure 1). Snapping Turtles sustained a single hole approximately 5–8 cm in diameter above the right, hind leg, which provided access to the internal organs. Northern Map Turtles and the Blanding's Turtle exhibited multiple entry wounds around the legs and cloaca and sustained lacerations to their necks and heads. The turtles' internal organs (oviduct, intestines, and sometimes liver) were removed. If the turtles had recently nested, the nests were also depredated. If the turtles had not yet nested, the eggs were pulled from the oviduct and eaten. In both cases, eggshells were left scattered around the carcasses. Not all carcasses were found immediately post mortem because some were concealed in vegetation and were found only after the carcass had already undergone some degree of autolysis.

We observed Raccoon tracks adjacent to several carcasses, and our wildlife cameras detected Raccoons patrolling the nesting site during the day and at night.



FIGURE 1. Six depredated Snapping Turtles (*Chelydra serpentina*) exhibiting entry wounds (5–8 cm diameter) characteristic of Raccoons (*Procyon lotor*), some with eggshells adjacent. Upper left example (a) shows Raccoon tracks adjacent to the carcass (white dotted circle). Photos: Christina Davy and Alyson Karsons.

During nesting surveys, we also made several observations of a Raccoon approaching, biting, or dragging gravid Northern Map Turtles. We suspect that a single Raccoon may have been responsible for all the observed mortalities, because the cluster of depredation events and the consistent locations of the entry wounds suggests a single individual and because the locations of the observed mortalities fall within a typical Raccoon home range (~200–400 ha; Šálek *et al.* 2015). The greatest distance between two depredated turtles was 3.25 km between a Northern Map Turtle and a Blanding's Turtle, which were depredated on 11 July and 12 July, respectively.

Discussion

The injuries we observed are consistent with those described for other depredation events in which Raccoons have been implicated (e.g., Seigel 1980; Pouliot *et al.* 2013). Gravid reptiles may be more susceptible to predation during extended overland movements toward nesting sites (Schwarzkopf and Shine 1992; Cox and Calsbeek 2009), but this is the first predator-related mortality of gravid or nesting females recorded at our study site in seven years of monitoring. It is unclear what prompted this Raccoon to expand its repertoire from nest depredation (>90% at our study site) to also preying on adult turtles. To our knowledge, this depredation event specifically targeted reproductive females, which are critical to population persistence (Brooks *et al.* 1991).

Nest depredation can be high even in relatively unimpacted, “natural” areas, and predation rates may increase in anthropogenically impacted habitats where mesopredators experience increased food supply (e.g., Raccoon or Coyotes scavenging from waste bins or agricultural fields). Subsidized mesopredators can live at higher densities, because the excess food increases the carrying capacity of those habitats (Smith and Engeman 2002). This in turn puts greater pressure on prey populations, and high nest predation rates resulting from subsidized predation can severely reduce recruitment into freshwater turtle populations (Marchand *et al.* 2002). If adult survivorship is high, the population may tolerate low recruitment rates (Heppell 1998). However, the addition of additive mortality in the form of depredation of adults would increase the probability of the population's eventual extirpation (Heppell 1998).

Our observations suggest that the additive mortality we describe here may have been caused by a single Raccoon, rather than an overabundance of Raccoons at Rondeau Park. A general overall reduction (i.e., culling) of this Raccoon population is unlikely to decrease rates of turtle or turtle nest predation. Experimental removal of Raccoons from areas adjacent to a sea turtle nesting beach did not decrease rates of nest predation because of rapid dispersal into the target site by individuals from nearby areas, coupled with rapid recruitment of juveniles to the surviving Raccoon population (Barton and

Roth 2007). Even a cull of 50% of the Raccoons present at a sea turtle nesting site failed to reduce nest depredation (Ratnaswamy *et al.* 1997). However, targeted removal of specific, predatory Raccoons and Armadillos (*Dasypus novemcinctus*) from another sea turtle nesting site managed to reduce nest loss from 95% to 9.4% (Engeman *et al.* 2005), suggesting that in some cases, ongoing adaptive predator control may be a useful tool for protecting turtle nests. As our observations appear likely to be caused by only one or a few Raccoons, targeting these specific individuals might alleviate future predation pressures on vulnerable females. However, although there is undoubtedly a relationship between subsidized mesopredator abundance and nest predation, we caution that Raccoons quickly learn new skills from one another and that the intense, targeted efforts required to effectively protect nesting females and their eggs would be costly to maintain.

The observed Snapping Turtle depredation ($n = 10$) represents ~1% of the estimated 800 females that nest at this site (C.M.D. unpubl. data), and our observations likely underestimate mortality because we may not have found all depredated individuals. Recurring predation events like this one could have rapid, cumulative effects on population viability, because turtle populations recover slowly or not at all from mass mortality events (Brooks *et al.* 1991). Mature females have the highest value in terms of population growth in freshwater turtles. Thus, the most critical conservation efforts may be those aimed at saving as many individual nesting turtles as possible (Heppell 1998), provided recruitment is also occurring (Bennett *et al.* 2017). Nevertheless, predation is an inevitable part of functioning ecosystems, and there is no way to eliminate this pressure completely. Considering rapid increases in additive mortality is essential to evaluating population viability, and pulses in depredation of adult turtles can have long-term effects on a population (Brooks *et al.* 1991). However, from the perspective of recovering threatened turtle populations, it is likely more effective to focus on the mitigation of the most consistent, significant sources of mortality, such as road mortality, or ongoing harvest in jurisdictions where turtles are still managed as game species.

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Variable habitat selection and movement patterns among Bullsna^{ke} (*Pituophis catenifer sayi*) populations in Saskatchewan

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Abstract

Pituophis catenifer sayi (Bullsna^{ke}) is a sparsely studied subspecies of conservation concern in Canada. Basic ecological information is lacking for *P. c. sayi*, which reaches its northern range limit in western Canada. To address this gap, we used radio-telemetry to examine space use and habitat selection in three populations of Bullsna^{kes} in disjunct river valley systems (Frenchman, Big Muddy, and South Saskatchewan River Valleys) across their Saskatchewan range. Bullsna^{kes} in two valleys used up to three times more space, travelled 2.5-times farther from overwintering sites, and had lower home range overlap than the third population. Landscape-level habitat selection was flexible, with snakes in all populations using both natural and human-modified habitats most frequently. Fine-scale habitat selection was also similar among populations, with Bullsna^{kes} selecting sites within 1 m of refuges, regardless of whether they were natural or anthropogenic. Based on these results, Bullsna^{kes} are flexible in their broad scale habitat use, as long as they are provided with fine scale refuge sites. The distribution of key seasonal resources appears to ultimately determine space use and habitat selection by Bullsna^{kes}, regardless of the geographic location of the population.

Key words: Bullsna^{ke}; *Pituophis catenifer sayi*; grassland snakes; habitat selection; home range; space use; ecology

Introduction

Pituophis catenifer sayi (Bullsna^{ke}) is widespread throughout North America, but is of conservation concern in Canada where it reaches its northern range limit. The Committee on the Status of Endangered Wildlife in Canada assessed this subspecies of Gophersna^{ke} (*Pituophis catenifer*) as Special Concern (COSEWIC 2017), and there is a corresponding need for basic ecological and population studies. Information from more southerly populations in the USA shows that space requirements (home range size) are highly variable for Bullsna^{kes} (Moriarty and Linck 1997; Fitch 1999; Rodriguez-Robles 2003; Kapfer *et al.* 2008, 2010). Kapfer *et al.* (2010) found that habitat quality was the most important factor affecting home range: Bullsna^{kes} in high quality areas used less space. Bullsna^{ke} habitat selection also varies across their range, with some populations selecting south facing bluffs (Kapfer *et al.* 2008), while others primarily select open grassland habitats (Moriarty and Linck 1997; Rodriguez-Robles 2003). Space and habitat use have been examined for the closely related Great Basin Gophersna^{ke} (*Pituophis catenifer deserticola*) in Canada (Williams *et al.* 2012, 2014, 2015), though only two studies have addressed space use and habitat selection by Bullsna^{kes} specifically. Both of these studies focussed on the same Bullsna^{ke} population in the Frenchman River Valley of southwestern Saskatchewan (Martino *et al.* 2012; Gar-

diner *et al.* 2013). These Bullsna^{kes} made long distance migrations between summer and winter habitats (up to 4 km), selected for lowland pasture, slopes, and roads, and relied heavily on mammal burrows as refuge sites (Martino *et al.* 2012; Gardiner *et al.* 2013). Bullsna^{ke} home ranges in the Frenchman River Valley were substantially larger than more southerly populations in the United States (up to 99 fold difference; Martino *et al.* 2012). However, it is currently unknown whether the space use and habitat selection by snakes in this one area are broadly reflective of other populations occupying various landscapes across their Canadian range.

Snake space use and habitat selection are primarily based on the spatial distribution of key resources in the environment, and thus vary within and among populations (Carfagno and Weatherhead 2006; Bauder *et al.* 2015; Gomez *et al.* 2015). For example, Prairie Rattlesna^{kes} (*Crotalus viridis viridis*) demonstrate variation in space use throughout their geographic range (displacement from overwintering site: 2.76 to 40 km; home range: 18 to 109 ha; Bauder *et al.* 2015), with variation in prey availability being the suggested driver for these differences. Occupancy has also been linked to thermal requirements, with snakes selecting habitats conducive to optimizing thermoregulation (Burger and Zappalorti 1992; Blouin-Demers and Weatherhead 2001; Carfagno and Weatherhead 2006; Blouin-Demers and Weatherhead 2008; Cross *et al.* 2015). Retreat sites

can be particularly critical as they provide suitable habitat for thermoregulation, refuge from predators, and increased foraging opportunities (Charland and Gregory 1995; Rodriguez-Robles 2003; Himes *et al.* 2006; Croak *et al.* 2013). The presence of refuges is especially important for snakes at northern latitudes, where the distribution and abundance of overwintering den sites often limits space use; snakes must move to and from suitable overwintering sites each year (Burger *et al.* 1988; Jorgensen *et al.* 2008; Bauder *et al.* 2015). As a result, the proximity of den sites relative to other key resources may be a primary determinant of space requirements in northern populations (Martino *et al.* 2012; Williams *et al.* 2012; Gardiner *et al.* 2013).

Space and habitat use by snakes may also be affected in various ways by human modification of the landscape or specific resources. The removal of native habitats can have negative impacts on abundance, activity patterns, and behaviours (Burger 2001; Kjooss and Litvaitis 2001; Beale *et al.* 2016). However, in many cases, responses vary depending on the ability of snakes to tolerate habitat changes and the quality of available resources (Driscoll 2004; Corey and Doody 2010). Ultimately, individuals may demonstrate increases, decreases, or no difference in the frequency of movements or extent of space use in human modified landscapes compared to natural landscapes (Corey and Doody 2010; Anguiano and Diffendorfer 2015; Smith *et al.* 2015; Ettling *et al.* 2016). Species may even be positively associated with modified habitats (Carfagno and Weatherhead 2006; Knoot and Best 2011). Snake response to habitat modification remains to be addressed thoroughly in areas with variation in human land use type and intensity.

Here, we quantify Bullsnake space use and habitat selection in populations from three different major river valley systems (Frenchman, Big Muddy, and South Saskatchewan River Valleys) in Saskatchewan, Canada. Our hypothesis was that habitat availability and landscape configuration, specifically the distance between overwintering dens sites and summer habitat, affect the space use and habitat selection of snakes. Consequently, we predicted that Bullsnake space use and habitat selection would vary among populations in the different river valleys, as these areas differ substantially in their available habitat types, landscape configurations, and intensity of human modification. Bullsnake spatial ecology has only been examined previously for one population in Canada, so our study aims to increase understanding of how these snakes use landscapes in various circumstances.

Methods

Study species

Bullsnakes are the largest snakes in Canada, reaching lengths of up to 2.5 m (Ernst and Ernst 2003). Bullsnakes are non-venomous constrictors that prey on small mammals, such as mice and ground squirrels, as well as birds, bird eggs, and reptiles. These snakes

are diurnal during the majority of the summer, but may become more active during crepuscular periods when conditions are exceedingly hot and dry (July and August). Bullsnakes are widespread throughout the United States, with their range extending northward into Canada, across southeast Alberta to southwest and south-central Saskatchewan (Ernst and Ernst 2003). Bullsnakes nest communally or individually under rocks, logs, and within self-excavated or mammal-created burrows (Ernst and Ernst 2003; Wright 2008). Bullsnakes overwinter in extensive mammal burrows or rock crevices (Ernst and Ernst 2003; Kapfer *et al.* 2008). In 2017 Bullsnakes were assessed as a species of Special Concern in Canada mainly due to threats of habitat loss and road mortality. Life history, behavioural, and population characteristics are thought to exacerbate the effects of these threats on Bullsnakes (COSEWIC 2017). As Bullsnakes den communally and may return to the same den each year, protection of these limited den sites is important for this subspecies.

Study areas

We studied Bullsnake space and habitat use in three major river valley systems across southern Saskatchewan, Canada: the Frenchman River Valley (FRV; in 2008 and 2009; data collected by Martino *et al.* 2012), the Big Muddy Valley (BMV; in 2015), and the South Saskatchewan River Valley (SSRV; in 2016; Figure 1). Bullsnakes rely on hibernacula in valley walls; the area between valleys likely does not contain suitable overwintering sites, and much of the habitat has been converted to agriculture. Bullsnakes in the three valleys are genetically differentiated, and no movement among populations is likely (Somers *et al.* 2017).

The study area in the FRV (49°10'37"N, 107°25'33"W) is located within a community pasture. This area is composed of large tracts of native grass pasture, surrounded by cropland and roads (paved and gravel). We tracked snakes from two communal overwintering den sites within the native grassland pasture; both were located in valley hillsides with significant hill slumping and large burrow systems (Martino *et al.* 2012; Gardiner *et al.* 2013). Overwintering sites in the FRV are separated from the riparian zone in the centre of the valley by ~3–4 km. To use habitat other than the hills and slopes associated with valley walls, Bullsnakes in the FRV need to travel long distances, and almost always move downslope toward the valley centre (Martino *et al.* 2012; Gardiner *et al.* 2013).

The BMV (49°12'55"N, 105°12'09"W) site is dominated by native grass pasture in the main valley and adjacent ravines. Cattle and horse ranches are located in the valley lowlands while the surrounding uplands have been converted for crop production. Bullsnakes are found on private land in this area. Ranchers in the BMV tend to protect Bullsnakes occupying their land due to the perceived rodent control benefits the snakes provide. We tracked snakes from den sites located in crevice and burrow systems within rock formations and valley hillsides. Communal den sites in the BMV

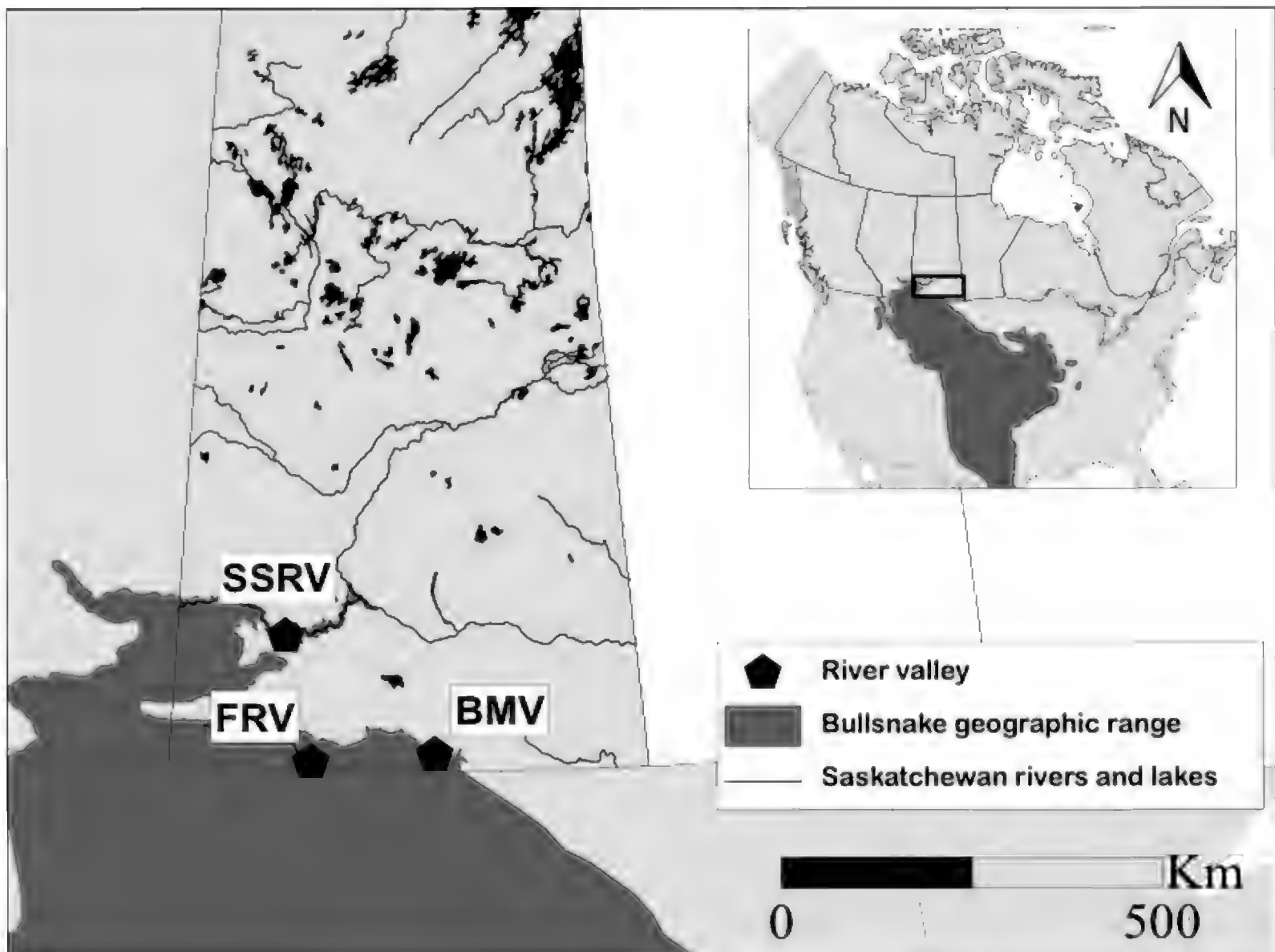


FIGURE 1. Location of study sites where Bullsnakes (*Pituophis catenifer sayi*) were tracked using radio-telemetry in southern Saskatchewan: Frenchman River Valley (FRV, 2008–2009, data collected by Martino *et al.* 2012), Big Muddy Valley (BMV, 2015), and South Saskatchewan River Valley (SSRV, 2016), indicated by the black pentagons. The North American Bullsnake range is highlighted in dark grey. Inset: the geographic range of Bullsnakes in Canada and the United States (dark grey).

were <500 m from the valley base and in ranch farmyards. Contrary to the SSRV and FRV, no large river runs through the BMV.

The study area in the SSRV (50°38'16"N, 107°59'28"W) is located in Saskatchewan Landing Provincial Park. The South Saskatchewan River has been converted into a large reservoir (Lake Diefenbaker) and this reservoir comprises the centre of Saskatchewan Landing Provincial Park, making it a popular area for summer recreational activities. The Provincial Park has ~250 000 visitors per year (D. Silversides pers. comm. 8 November 2016). Native prairie dominates the main valley and adjacent coulees. Visitor areas (including campgrounds, a golf course, and cottages) are also found throughout the base of the valley. The uplands surrounding the park are used for cattle ranching and crop production. Den sites throughout the park are found within burrow systems (this study; Royal Saskatchewan Museum unpubl. data). Den sites are found in a wide range of locations, some of which are relatively close to the valley base (~100–600 m from Lake Diefenbaker) and in various topographies, from hillsides to flat, native grass fields (this study; Royal Saskatchewan Museum unpubl. data).

Snake capture and transmitter implantation

We located Bullsnakes during their active season (April to October) using foot searches and road surveys in the FRV from 2008 to 2009 (Martino *et al.* 2012), the BMV in 2015, and the SSRV in 2016. Upon capture, snakes were measured, weighed, sexed (after Schaefer 1934), and implanted with Passive Integrated Transponder (PIT) tags. Snakes were transported to a veterinary clinic and surgically implanted with Holohil model SI-2 (Carp, Ontario, Canada), 13-g radio-transmitters (similar to Lentini *et al.* 2011) by veterinary surgeons. In 2016, implantation protocols were modified, such that the transmitter wire was implanted within the body cavity of the snake instead of under the integument. This modification was made because subcutaneous implantation of the transmitter wire may lead to wire penetration of the skin and subsequent infection (Lentini *et al.* 2011). Snakes were only implanted if the diameter of the transmitter was <50% of the body diameter at the implantation site, and the mass of the transmitter was <5% of body mass. Snakes were allowed a minimum of 24 h recovery, upon which they were released at their original capture location.

Space use and movement patterns

Following release, we relocated Bullsnares every 48 h (when possible) for the duration of their summer active season. After snakes had returned to den sites in the fall (late August to early October), tracking was reduced to once every 1 to 2 weeks. Upon each relocation of a snake, we recorded universal transverse mercator (UTM) coordinates on a Garmin Legend HCx (Lenexa, Kansas, USA) handheld global positioning system (GPS) unit (± 2 m). We quantified Bullsnares movement patterns using ArcGIS 10.3.1 (ESRI 2015). Maximum displacement by individual snakes from their respective den sites was calculated using the Point Distance Tool. The Geospatial Modelling Environment (GME; Beyer 2015) was used to estimate 100% minimum convex polygons (MCP), as well as 50% and 95% kernel density estimates (KDE). MCP was calculated for individuals with at least 10 relocations (Himes *et al.* 2006; Parker and Anderson 2007; Kapfer *et al.* 2008, 2010; Martino *et al.* 2012) and KDE for individuals with at least 15 relocations (as in Gardiner *et al.* 2013). We defined relocations as any location to which a snake was tracked. We performed regression analysis to determine if the number of relocations per snake affected home range size (Kapfer *et al.* 2008). There was no significant positive relationship between home range size and the number of observations per snake (data not shown).

For the KDE, smoothing factors for each snake were estimated using the Plugin algorithm, which calculates the X and Y variances as well as the X/Y covariance among relocation UTM coordinates. We used this method to calculate smoothing factors, as the commonly used least squared cross-validation (LSCV) algorithm tends to oversmooth and is not recommended for individuals with multiple relocations at the same site (Row and Blouin-Demers 2006). Using the Plugin algorithm to calculate a smoothing factor also produced 95% KDE areas that were most similar to MCP areas, compared to the LSCV.

We calculated home range overlap for all river valleys using two different methods. The distances between Bullsnares MCP centroids were calculated using the Point Distance Tool, and the proportion of MCP shared was calculated using the Intersect Tool in ArcGIS. Distance between centroids and proportion of home range overlap was calculated for Bullsnares occupying the same den sites. We constructed generalized linear models (GLM, with a gamma distribution) to estimate which variables influence snake home range size (MCP; 95% KDE; 50% KDE) and maximum displacement of snakes from den sites. Fixed effects were snake sex, snout-to-vent length, distance to nearest anthropogenic structure (i.e., farmyards, campgrounds, parking lots, cottages), and river valley. Distance to nearest anthropogenic structure was calculated as the distance between the centroid of an individual snake's MCP and the nearest anthropogenic structure point feature

using the Point Distance Tool. After running the global model, we used Akaike's Information Criterion corrected for small samples size (AICc) for model selection. Competing models with $\Delta AICc < 10$ were model averaged and the 95% CI calculated (Burnham *et al.* 2011). We also performed gamma and beta regression analyses, respectively, to estimate which variables influence centroid distance and proportion of home range overlap.

Third order habitat selection: compositional analysis

Third order selection is defined as selection of habitats distinguishable by larger scale features, such as topography and vegetation type (Johnson 1980). Habitat selection at this scale was examined using compositional analysis; comparing the number of observations in each habitat type to the proportion of each habitat type available to Bullsnares (Aebischer *et al.* 1993). Available habitat types were defined and distinguished prior to snake tracking using aerial imagery and confirmed in the field. Habitats were considered to be available to a snake if they were contained within a circular buffer zone centred on the den site that was calculated to be the maximum displacement by snakes in the corresponding population (5 km radius buffer in the FRV; 1.3 km buffer in the BMV; 2.4 km buffer in the SSRV; Gomez *et al.* 2015). Third order habitat selection by Bullsnares in the FRV was measured by Gardiner *et al.* (2013), where available habitats included riparian areas, hills/slopes, native lowland grass pasture, mudflats, roads, irrigation areas, native upland fields, crop fields, Prairie Dog (*Cynomys ludovicianus*) towns, and open water. Habitats available to snakes in the BMV included native grass pasture, crop fields, roads/road areas, hills/slopes/rock formations, trees/tall shrubs, and farmyards. SSRV habitats included native prairie, tame grass fields, mowed areas, human-developed areas (such as parking lots, buildings, and campgrounds), crop fields, roads/road areas, beach area, trees/tall shrubs, marshes/streams, and open water.

Polygons encompassing available habitats within buffer zones were traced on a high-resolution satellite image (downloaded from <https://www.flysask2.ca>; accessed 10 September 2016) in ArcGIS. The proportion of each habitat within the buffer zone was calculated (defined as proportion available), as well as the proportion of total observations for each individual snake within each habitat type (defined as proportion used). We used the adehabitatHS package in R (Calenge 2006) to perform compositional analysis to test for non-random habitat use (selection) and rank habitats based on their selection by Bullsnares.

Fourth order habitat selection

Fourth order habitat selection is defined as the selection of the immediate and local habitat, comprised of physical and ecological features that distinguish it from the surrounding environment (Johnson 1980). A used versus available study design was followed to quantify

total relocations per individual ranging from 43 to 55 (Table 1). In the SSRV, 14 Bullsnares (six females, eight males) were implanted with radio-transmitters. The number of relocations per snake ranged from 12 to 48 (Table 1). The maximum time between tracking events was 19 days in the FRV, seven days in the BMV, and six days in the SSRV.

Space use and movement patterns

The GLM indicated the largest factor affecting displacement from den sites by Bullsnares was the river valley they occupied (Table 2). Bullsnares in the FRV (493 to 3946 m) and SSRV (661 to 2427 m) had similar and relatively long maximum displacements from overwintering den sites, moving up to 2.7 times farther from dens than Bullsnares in the BMV (Figure 2).

Fourteen snakes in the FRV, seven snakes in the BMV, and 14 snakes in the SSRV were relocated often enough to estimate MCPs, while 10 FRV, seven BMV, and 13 SSRV snakes had enough relocations to estimate the 50% and 95% KDEs. Generalized Linear Models examining differences in home range size among Bullsnares, regardless of home range estimator, were consistent with analyses of den site displacement, indicating river valley as the only fixed effect (Table 3; Tables S1 and S2). On average, Bullsnares in the FRV and SSRV had MCP home ranges up to 3.7 times larger, 95% KDEs up to 4.5 times larger, and 50% KDEs up to 4.4 times larger than those in the BMV (Table 1; Figure 2).

Home range overlap was greater on average in the BMV, compared to the FRV and SSRV (Table 1; Figure 2). This was supported by generalized linear regression analyses, which demonstrated that the distance between centroids increased (FRV Estimate = 799.08, $P < 0.001$; SSRV Estimate = 540.89, $P < 0.001$) and the proportion of home range overlap decreased (FRV

Estimate = -1.66, $P < 0.001$; SSRV Estimate = -1.39, $P < 0.001$) in the FRV and SSRV compared to the BMV.

Third order habitat selection

Native lowland grass pasture, hills/slopes, and roads were used most frequently by Bullsnares in the FRV (Figure 3a; Martino *et al.* 2012; Gardiner *et al.* 2013). Bullsnares in the BMV also exhibited non-random habitat use ($\lambda = 0.002$, $P = 0.04$); the most frequently used habitat types were farmyards and native grass pasture. On average, farmyards were selected 11 times more than expected; native grass pasture, roads, and hills/slopes were used in proportion to availability; and crop fields and treed areas were not used at all (Figure 3b). Similarly, Bullsnares in the SSRV also exhibited non-random habitat use ($\lambda = 0.014$, $P = 0.01$); the most frequently used habitats were beach area, native prairie, tame grass fields, human-developed areas (including buildings, parking lots, and campgrounds), mowed areas, and roads. Bullsnares used beaches 91.6 times, tame grass fields 8.7 times, buildings 2.1 times, mowed areas 2.9 times, and roads 2.3 times more than expected based on availability (Figure 3c). Native prairie and marshes were used in proportion to availability; while treed areas and crop fields were used 8.7 times and two times less than expected (Figure 3c). Snakes were not observed in open water; however, they did make use of this habitat to travel from one side of Lake Diefenbaker to the other.

Fourth order habitat selection

The top model explaining differences between used and available sites in the BMV and SSRV included percent grass cover, vegetation density, and distance to the nearest burrow (Tables 4 and 5). The probability of occupancy increased with decreasing grass cover, increasing vegetation density, and decreasing distance to the

TABLE 2. Top generalized linear model, null model, and all models with $\Delta AIC \leq 2$ evaluating the best predictor of maximum displacement from overwintering den sites by Saskatchewan Bullsnares (*Pituophis catenifer sayi*). Fixed effects included river valley (BMV is reference valley), distance to nearest anthropogenic structure (dist. a), snout-to-vent length (svl), and snake sex (M = male). Number of model parameters (K), AICc, difference in AICc from top model (ΔAIC), Akaike weights, parameter estimates, SE, upper and lower 95% CI, and importance values are presented. Factors with largest effect in bold.

Model		K	AICc	ΔAIC		Weights
AIC model selection	Intercept only	1	501.50	9.57		0.00
	valley + dist. a	2	491.92	0.00		0.37
	valley	1	492.95	1.03		0.22
	valley + dist. a + svl	3	494.07	2.15		0.13
Model averaging	Parameter	Estimate	SE	Lower 95% CI	Upper 95% CI	Importance values
	(Intercept)	6.34	0.42	5.62	7.05	NA
	FRV	1.21	0.34	0.64	1.78	0.99
	SSRV	0.88	0.27	0.43	1.34	0.99
	dist. a	0.00	0.00	0.00	0.00	0.61
	svl	0.00	0.00	0.00	0.01	0.26
	sexM	0.00	0.09	−0.16	0.16	0.19

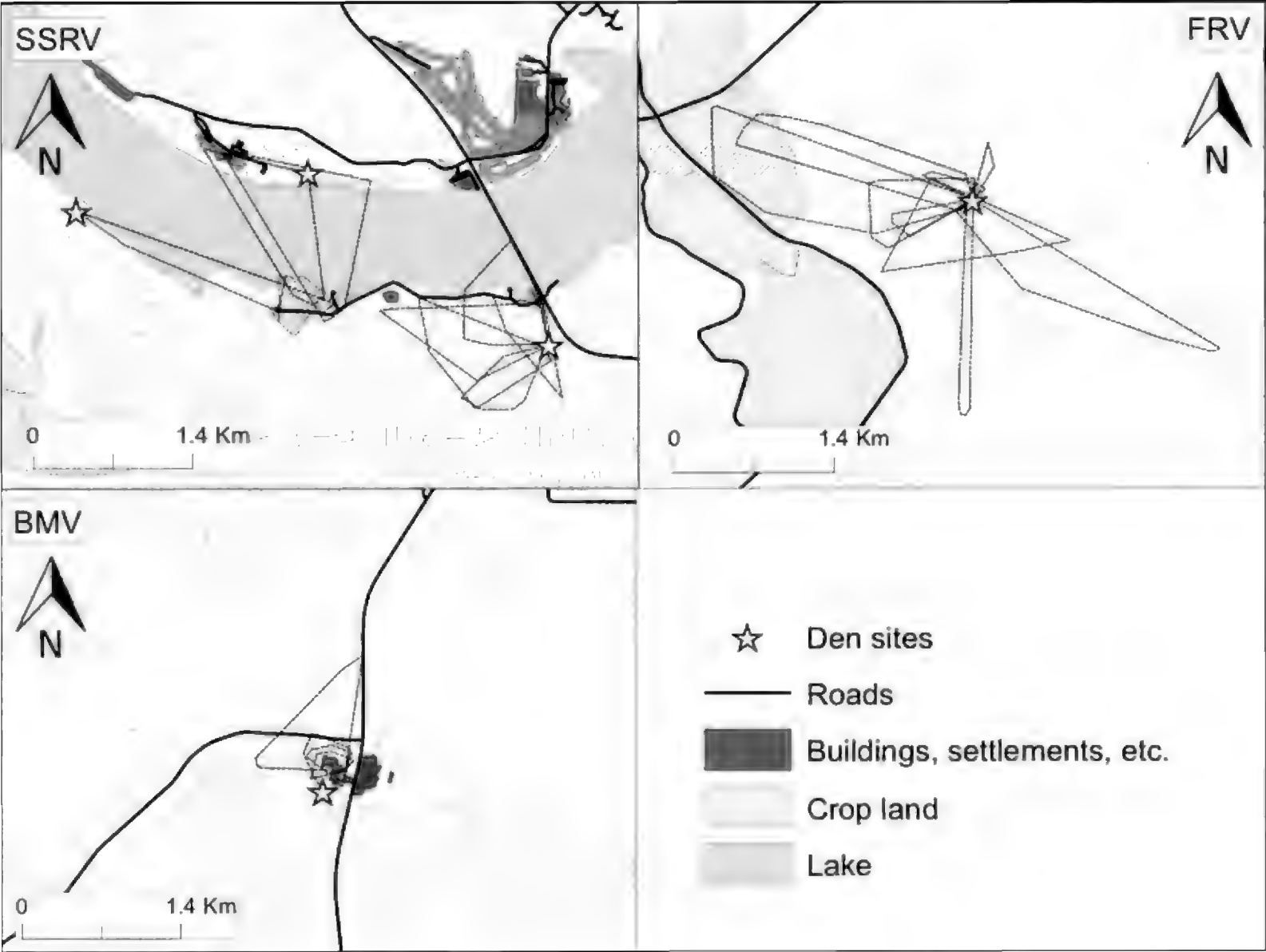


FIGURE 2. Minimum convex polygons (MCPs) for Bullsnakes (*Pituophis catenifer sayi*) in the Frenchman River (FRV), South Saskatchewan River (SSRV), and Big Muddy (BMV) Valleys. MCPs are shown for nine FRV, eight SSRV, and four BMV Bullsnakes to depict variation in home ranges observed. Den sites are indicated by stars, roads by thick black lines, human developed areas by dark grey polygons, crop fields by crosshatched polygons, lakes by light grey polygons, and contours lines by light grey lines.

TABLE 3. Top generalized linear model, null model, and all models with $\Delta AIC \leq 2$ evaluating the best predictor of Saskatchewan Bullsnake (*Pituophis catenifer sayi*) 95% kernel density home range estimate. Fixed effects included river valley (BMV is reference valley), distance to nearest anthropogenic structure (dist. a), snout-to-vent length (svl), and snake sex (M = male). Number of model parameters (K), AICc, difference in AICc from top model (ΔAIC), Akaike weights, parameter estimates, SE, upper and lower 95% CI, and importance values are presented. Factors with largest effect in bold.

Model		K	AICc	ΔAIC		Weights
AIC model selection	Intercept only	1	266.50	7.24		0.01
	valley + svl	2	259.42	0.00		0.39
	valley	1	261.43	2.16		0.13
Parameter		Estimate	SE	Lower 95% CI	Upper 95% CI	Importance values
Model averaging	(Intercept)	4.00	1.18	2.03	5.97	NA
	FRV	1.71	0.53	0.81	2.60	0.97
	SSRV	1.32	0.44	0.57	2.07	0.97
	svl	-0.01	0.01	-0.03	0.01	0.63
	dist. a	0.00	0.00	0.00	0.00	0.28
	sexM	-0.09	0.24	-0.49	0.31	0.25

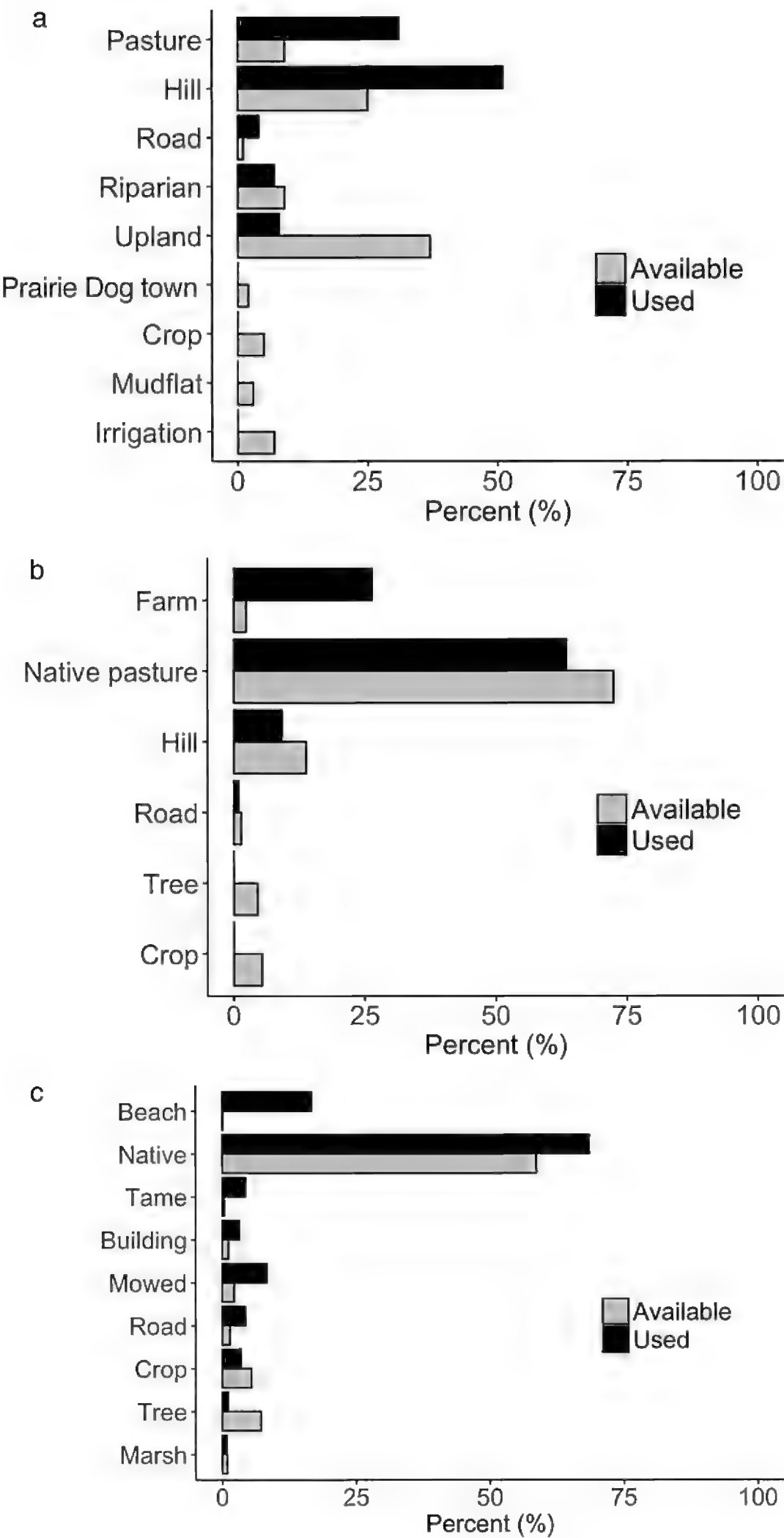


FIGURE 3. Third order habitat selection by Bullsnares (*Pituophis catenifer sayi*) in three Saskatchewan river valleys. a. Percent of different habitats used and available within a 5 km buffer surrounding den sites in the Frenchman River Valley. b. Percent of different habitats used and available within a 1.3 km buffer surrounding den sites in the Big Muddy Valley. c. Percent of different habitat types used and available within a 2.4 km buffer surrounding den sites in the South Saskatchewan River Valley within Saskatchewan Landing Provincial Park.

TABLE 4. Top generalized linear mixed model, null model, and all models with $\Delta\text{AIC} \leq 2$ evaluating Bullsnake (*Pituophis catenifer sayi*) habitat selection in the Big Muddy Valley. Fixed effects included % grass cover, % shrub cover, % forb cover, distance to nearest burrow, distance to nearest shrub, maximum vegetation height, and Robel pole vegetation density. Random effect was individual snake ID (|ind|). Number of model parameters (K), AICc, difference in AICc from top model (ΔAIC), Akaike weights, parameter estimates, SE, upper and lower 95% CI, and importance values are presented. Factors with largest effect in bold.

Model			K	AICc	Δ AIC	Weights
AIC model selection	Intercept + ind		2	373.88	108.72	0.00
	density + % grass + burrow + ind		4	265.17	0.00	0.24
	dist. shrub + density + % grass + burrow + ind		5	266.58	1.42	0.12
	max veg + density + % grass + burrow + ind		5	266.89	1.72	0.10
	% forb + density + % grass + burrow + ind		5	267.01	1.84	0.10
	% shrub + density + % grass + burrow + ind		5	267.25	2.09	0.08
Model averaging	Parameter	Estimate	SE	Lower 95% CI	Upper 95% CI	Importance values
	(Intercept)	1.60	0.35	1.02	2.18	NA
	burrow	−0.51	0.09	−0.66	−0.37	0.99
	grass	−0.02	0.01	−0.03	−0.01	0.99
	density	3.83	1.89	0.71	6.95	0.98
	dist.shrub	0.01	0.01	−0.02	0.03	0.33
	max.veg	0.00	0.01	−0.01	0.02	0.30
	forb	0.00	0.01	−0.02	0.02	0.27
	shrub	0.00	0.01	−0.02	0.02	0.26

TABLE 5. Top generalized linear mixed model, null model, and all models with $\Delta\text{AIC} \leq 2$ evaluating Bullsnake (*Pituophis catenifer sayi*) habitat selection in the South Saskatchewan River Valley. Fixed effects included % grass cover, % shrub cover, % forb cover, distance to nearest burrow, distance to nearest shrub, maximum vegetation height, and Robel pole vegetation density. Random effect was individual snake ID (|ind|). Number of model parameters (K), AICc, difference in AICc from the top model (ΔAIC), Akaike weights, parameter estimates, SE, upper and lower 95% CI, and importance values are presented. Factors with largest effect in bold.

Model		K	AICc	ΔAIC	Weights	
AIC model selection	intercept + ind	2	539.07	123.86	0.00	
	burrow + % forb + % grass + max veg + density + ind	6	415.24	0.00	0.11	
	burrow + % grass + max veg + density + ind	5	415.31	0.07	0.11	
	burrow + % forb + %grass + density + ind	5	415.44	0.20	0.10	
	burrow + % grass + max veg + density + % shrub + ind	6	415.78	0.54	0.09	
	burrow + % forb + % grass + max veg + density + % shrub + ind	7	416.23	0.99	0.07	
	burrow + % forb + % grass + density + % shrub + ind	6	416.53	1.30	0.06	
	burrow + % grass + density + ind	4	416.81	1.57	0.05	
	burrow + dist. shrub + % grass + max veg + density + ind	6	417.16	1.92	0.04	
	burrow + dist. shrub + % forb + % grass + max veg +density + ind	7	417.18	1.95	0.04	
Model averaging	Parameter	Estimate	SE	Lower 95% CI	Upper 95% CI	Importance values
	(Intercept)	0.98	0.35	0.41	1.55	NA
	burrow	−0.16	0.02	−0.19	−0.13	0.99
	grass	−0.01	0.01	−0.02	0.00	0.89
	density	0.81	0.29	0.33	1.29	0.98
	max.veg	0.01	0.01	0.00	0.02	0.58
	forb	0.02	0.02	−0.02	0.05	0.56
	shrub	0.00	0.01	−0.01	0.01	0.38
	dist.shrub	0.00	0.01	−0.01	0.01	0.27

nearest burrow. The model-averaged 95% CI for distance to nearest burrow, percent grass cover, and vegetation density did not pass through zero for both river valleys and the importance values for these three variables were greater than 0.8 (Tables 4 and 5). Bullsnakes were most likely to be found within 1 m of a burrow or other refuge site (76% of the time in BMV, 73% of the time in SSRV).

Discussion
Bullsnake space use and movement patterns vary across their geographic range. Two populations in our study used more space than Bullsnakes in more southerly areas (Moriarty and Linck 1997; Fitch 1999; Rodriguez-Robles 2003; Kapfer *et al.* 2008; mean MCP: 34.43 ± 27 ha, mean 95% KDE: 71.81 ± 62 ha), while the third population used less or similar space compared

to southern populations. As such, northern populations do not appear to consistently tend towards larger home ranges, as originally suggested (Martino *et al.* 2012; Gardiner *et al.* 2013). We also found individual variation in snake space use patterns within and among sites even over a small geographic scale, similar to what has been previously observed (Bauder *et al.* 2015; Gomez *et al.* 2015). Some snakes used very little space, similar to southern populations (Rodriguez-Robles 2003; Kapfer *et al.* 2008), while others required much larger home ranges (MCP up to 175 ha). Williams *et al.* (2012) found similar variation in space use among neighbouring populations of the closely related Great Basin Gophersnake. In the case of our study and Williams *et al.* (2012), variation in home range size was strongly associated with study site, and appears to be the result of corresponding variation in distance between overwintering and summer habitats/resources.

Multiple factors may be driving this variation in Bullsnake space use, including den/nest site connectivity and prey availability. Previously, prey was identified as a driver of snake space use, with smaller home ranges in areas of higher prey availability (Brown *et al.* 2005; Wisler *et al.* 2008; Baxley and Qualls 2009; Ettling *et al.* 2016). Though no formal surveys were conducted, we observed abundant prey in the den-adjacent farmyards occupied by Bullsnares in the BMV. We also observed mating and gravid Bullsnares in this area. This suggests that the smaller home ranges of Bullsnares in the BMV may be due to a tighter spatial connection between seasonal resources (i.e., overwintering dens and prey/nest sites). Higher resource availability in a small area near den sites in the BMV also corresponds with our home range overlap data (Figure 2). Bullsnares in the BMV had higher home range overlap, in addition to smaller home ranges, suggesting a sufficient availability of resources capable of supporting individuals in close proximity to dens. In contrast, summer and overwintering activity centres (in terms of the 95% KDE) were separate in the FRV and SSRV, resulting in seasonal migrations (as described in Gardiner *et al.* 2013). Home range overlap was also lower, with snakes using different areas during the active season. Snakes have been observed to migrate seasonally to locate prey in areas of low prey density (Duvall *et al.* 1990), similar to what we observed in the FRV and SSRV. Williams *et al.* (2012) also suggested that Great Basin Gophersnake movements differed among sites due to differences in food availability and predation pressures. In addition, Kapfer *et al.* (2010) suggested that Bullsnake space use may be driven by thermoregulatory and refuge needs. Regardless of driving factor, the placement of den sites in relation to active season resources appears to be a primary determinant of Bullsnake space use.

Bullsnares are flexible in their broad scale habitat use. Here, we found various human-modified habitats to be selected for by snakes in the BMV and SSRV, in addition to habitats dominated by native vegetation that

were the most frequently used, though not necessarily selected because they were typically used according to their availability (Figure 3b and c). Comparably, Bullsnares in the FRV selected primarily for native habitats, in addition to roads (Figure 3a; Gardiner *et al.* 2013). Similarly, in Canada, Great Basin Gophersnares use primarily native grassland habitat, in addition to slopes (Williams *et al.* 2014, 2015). Previous studies in southern range areas have also found Bullsnares to use primarily native grassland habitats (Moriarty and Linck 1997; Rodriguez-Robles 2003; Kapfer *et al.* 2008). Slopes with native vegetation in particular appear to provide important overwintering habitat for Bullsnares (Kapfer *et al.* 2008; Martino *et al.* 2012; Gardiner *et al.* 2013; our study). As such, native grassland habitat appears to be universally important for Bullsnares across their range.

Retreat sites are an important habitat feature for Bullsnares. Snakes in the BMV and SSRV selected for sites in close proximity to retreat sites, regardless of other habitat features or whether the refuge itself was natural (mammal burrow) or anthropogenic (under walkways, cement pads, stacked rocks). Bullsnares in the FRV also demonstrated a dependence on retreat sites, as did Eastern Yellow-bellied Racers (*Coluber constrictor flaviventris*) and Prairie Rattlesnares in the same areas (Martino *et al.* 2012; Gardiner *et al.* 2015). Suitable retreat sites are an important habitat feature for snakes, as they provide refuge from extreme temperatures and benefit thermoregulation (Huey *et al.* 1989; Webb and Shine 1998; Himes *et al.* 2006; Blouin-Demers and Weatherhead 2008; Croak *et al.* 2013). In our study, Bullsnares remained near retreat sites (within 1 m), even when snakes were not located directly within the retreat site itself. This would be beneficial for thermoregulation, as it would allow snakes to move in and out of refuges, depending on their physiological and thermoregulatory needs (Blouin-Demers and Weatherhead 2001). Remaining close to retreat sites, particularly burrows, would also benefit Bullsnares by allowing them to avoid predators and hunt rodent prey that occupy the burrows (Moriarty and Linck 1997; Rodriguez-Robles 2002; Heard *et al.* 2004; Himes *et al.* 2006). Of the retreat sites used by Bullsnares, many were created via excavation by mammals. Large burrow networks may also be used as overwintering sites (Moriarty and Linck 1997; Williams *et al.* 2015). As a result, snake reliance on mammal-created refuge sites supports the importance of burrowing mammals, such as the Richardson's Ground Squirrel (*Urocitellus richardsonii*), Nuttall's Cottontail (*Sylvilagus nuttallii nuttallii*), and American Badger (*Taxidea taxus*), for Bullsnake survival.

Vegetation density and grass cover also appear to affect fine scale habitat selection by Bullsnares. Decreased grass cover at selected sites in the BMV and SSRV is most likely a consequence of Bullsnake retreat site selection. The majority of retreat sites are typically

grass free; bare ground surrounds excavated burrow entrances and anthropogenic retreat sites are constructed of cement and other materials, with little vegetation. Increased vegetation density on selected sites in our study likely reflects shrub cover, particularly the dense sagebrush common in our study areas. Snakes have previously been observed to select for sites within close proximity to shrubs as well as retreat sites (Harvey and Weatherhead 2006; Martino *et al.* 2012; Gardiner *et al.* 2015) and many of the excavated burrows used by Bullsnakes in the BMV and SSRV were located at the base of shrubs, suggesting their potential benefit. One such benefit may be thermoregulation; as sun penetrates the shrubs and warms the snake, the shrub itself provides additional cover from predators (Huey *et al.* 1989). Burrows located beneath shrubs may also receive structural support from roots, which may be important for snakes in areas of high cattle density, such as the BMV.

The introduction of human-modified habitats and anthropogenic features is potentially beneficial to snakes. For example, snakes in the SSRV were found under walkways, in parking lots under cement blocks, and under buildings. Snakes using these retreat sites occupied them over relatively long periods of time (weeks), potentially indicating that they were suitable for thermoregulation and for meeting other needs. Previous research has found that snakes use artificial structures on the landscape, such as buildings and wells, as overwintering den sites (Woodbury and Parker 1956; Costanzo 1986; Burger *et al.* 1988). Modified habitats may also yield increased prey densities, which in turn attract and benefit snakes (Corey and Doody 2010). However, use of these habitats may also be costly for snakes. The use of anthropogenic habitat features in areas of high human activity could potentially increase risk of mortality via snake-vehicle collisions or human persecution. The consumption of rodent prey (e.g., ground squirrels) in agricultural areas may also be detrimental, as snakes may be exposed to rodenticide poison through prey consumption (Bishop *et al.* 2016). When assessing how the introduction of modified habitats will affect snake populations, researchers should consider the potential threats to snakes making use of these introduced habitat features.

Conclusions

Bullsnake space requirements vary among populations as well as across their geographic range. Much of the time, data pertaining to space use by a species are based on one population or study site (Croak *et al.* 2013). Here, we highlight the importance of understanding the spatial ecology of different populations of the same species, as resource distribution may differ greatly among populations. These findings are also relevant to other snake species that demonstrate similar variability in space use (Jorgensen *et al.* 2008; Bauder *et al.* 2015; Gomez *et al.* 2015). As a result, conservation and management strategies developed for one population of a species or subspecies may not be applicable

to others. Williams *et al.* (2012) found similar results, examining the effectiveness of wildlife habitat areas encompassing Great Basin Gophersnake den sites. Though the majority of gophersnakes were protected within these areas, certain individuals travelled outside of the allocated area (Williams *et al.* 2012). How to consider variance in habitat and space use among populations when developing conservation strategies remains to be addressed. A possible approach for implementing a more inclusive strategy would be to create protected buffers around den sites, based on the largest measured space use requirements for a species, to encompass both wide and narrow-ranging individuals and populations.

Bullsnakes are quite generalist in their habitat requirements, making use of a range of native and modified habitats as shown in the current and previous studies (Moriarty and Linck 1997; Rodriguez-Robles 2003; Kapfer *et al.* 2008; Martino *et al.* 2012; Gardiner *et al.* 2013). The spatial association among seasonal habitats appears to be an important determinant of Bullsnake space use. However, the specific active season resource requirements driving the seasonal migrations of Bullsnakes, or lack thereof, remain to be addressed. Measuring how active season resource availability varies among populations may be useful in uncovering the drivers of Bullsnake space and habitat use during the active season. At the local scale, retreat sites were a universally important habitat feature, regardless of refuge type (i.e., natural or anthropogenic). We recommend considering fossorial mammal populations when developing management strategies for Bullsnakes, as they are important for providing food and refuges. We also recommend considering the consequences of Bullsnakes potentially making use of anthropogenic habitat features and refuge sites. Overall, habitat features at the fine spatial scale appear to be an important determinant of Bullsnake habitat use, compared to habitat features at the landscape scale.

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SUPPLEMENTARY MATERIAL:

TABLE S1. Top generalized linear model, null model, and all models with $\Delta AIC \leq 3$ evaluating the best predictor of Saskatchewan Bullsnake (*Pituophis catenifer sayi*) 50% kernel density core area size.

TABLE S2. Top generalized linear model, null model, and all models with $\Delta AIC \leq 2$ evaluating the best predictor of Saskatchewan Bullsnake (*Pituophis catenifer sayi*) minimum convex polygon home range size.

Incidentally gathered natural history information on Bullsnares (*Pituophis catenifer sayi*) in southeastern Alberta

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Abstract

We present observations on Bullsnares (*Pituophis catenifer sayi*) gathered during a study of Prairie Rattlesnares (*Crotalus viridis*) in a multiple-use, mixed grass landscape adjacent to the South Saskatchewan River, ~30 km northeast of Medicine Hat, Alberta, in May–October 1997. Hibernacula shared with rattlesnares were located close to the river. We captured 31 Bullsnares, either in a drift fence array around a hibernaculum or by hand; three were recaptured once. Emergence from the hibernaculum ended in mid-May, and return to it began in early September. A gap in capture events occurred between early July and late August, possibly attributable to fossorial activity during the height of the summer. The sex ratio of captured adult snakes was 0.64 in favour of males. Males attained the greatest maximum body sizes, but there was no significant size dimorphism by sex. Bullsnares were assignable to juvenile, subadult, and adult classes by body size. Most captures were made on slopes in the immediate vicinity of the river, in areas classed as “thin breaks”, but four captures, about 7 km east of the river, provide evidence of long-distance movements from hibernacula. Captures were seldom made in the vicinity of anthropogenic features. Gas field development has increased greatly in the years since these data were collected. Our findings provide a baseline for Bullsnares population responses to such changes.

Key words: Bullsnares; *Pituophis catenifer sayi*; habitat; size distribution; hibernacula; landscape use; human interactions; Alberta

Introduction

Gophersnares (*Pituophis catenifer*) is a large oviparous constrictor occupying a variety of habitats across much of western North America (Ernst and Ernst 2003). Populations are divided geographically among several subspecies (Ernst and Ernst 2003). In Alberta, populations of Bullsnares (*P. c. sayi*) are found scattered throughout the dry mixed grass and mixed grass subregions of the Grassland Natural Region, clustering around the vicinities of badlands terrain and major and minor river valleys (Russell and Bauer 2000; Kissner and Nicholson 2003; COSEWIC 2017). Summaries of what is known of Bullsnares ecology in Alberta are provided by Kissner and Nicholson (2003), Wright (2008), and COSEWIC (2017). Fortney *et al.* (2012), Martino *et al.* (2012), Gardiner *et al.* (2013), and Somers *et al.* (2017) have examined various aspects of Bullsnares habitat use and movement in southeastern Saskatchewan.

Bullsnares is currently considered to be a species of special concern (COSEWIC 2017). There is evidence of recent range contraction in Alberta (Russell and Bauer 2000; Kissner and Nicholson 2003) and reason for concern over the continuing impact of human activities. Oil and gas field development in the habitat of Bullsnares, with concomitant mortality from increased road traffic, is seen as the principal threat (Didiuk 2003;

Kissner and Nicholson 2003; Alberta Wild Species General Status Listing 2015; COSEWIC 2017). In Alberta, Bullsnares has held “sensitive” status since 2006 (Alberta Wild Species General Status Listing 2015).

In this contribution, we report observations (size and sex distributions, activity over the season, thermal biology, habitat use, and distribution across the landscape) of the Bullsnares population collected incidentally in 1997, during a study of Prairie Rattlesnares (*Crotalus viridis*) in southeastern Alberta (Powell *et al.* 1998). We include additional data and analyses as Supplemental Materials: patterns in morphology (sections S1 and S2), capture situation (section S3), environmental temperatures (section S4), and the characteristics of various sites and the number of Bullsnares caught in those sites (section S5). These additional data go beyond the main goal of this manuscript, but may be useful to others studying Bullsnares.

Study Area

The study area was about 30 km northeast of Medicine Hat, Alberta, in a region of rolling mixed range and cropland, bounded on the west by the South Saskatchewan River (Figure 1); latitude and longitude for the centre of the mapped area: 50.21°N, 110.56°W. This area has large coulees running to the east and northeast from the river channel, where the South Sas-

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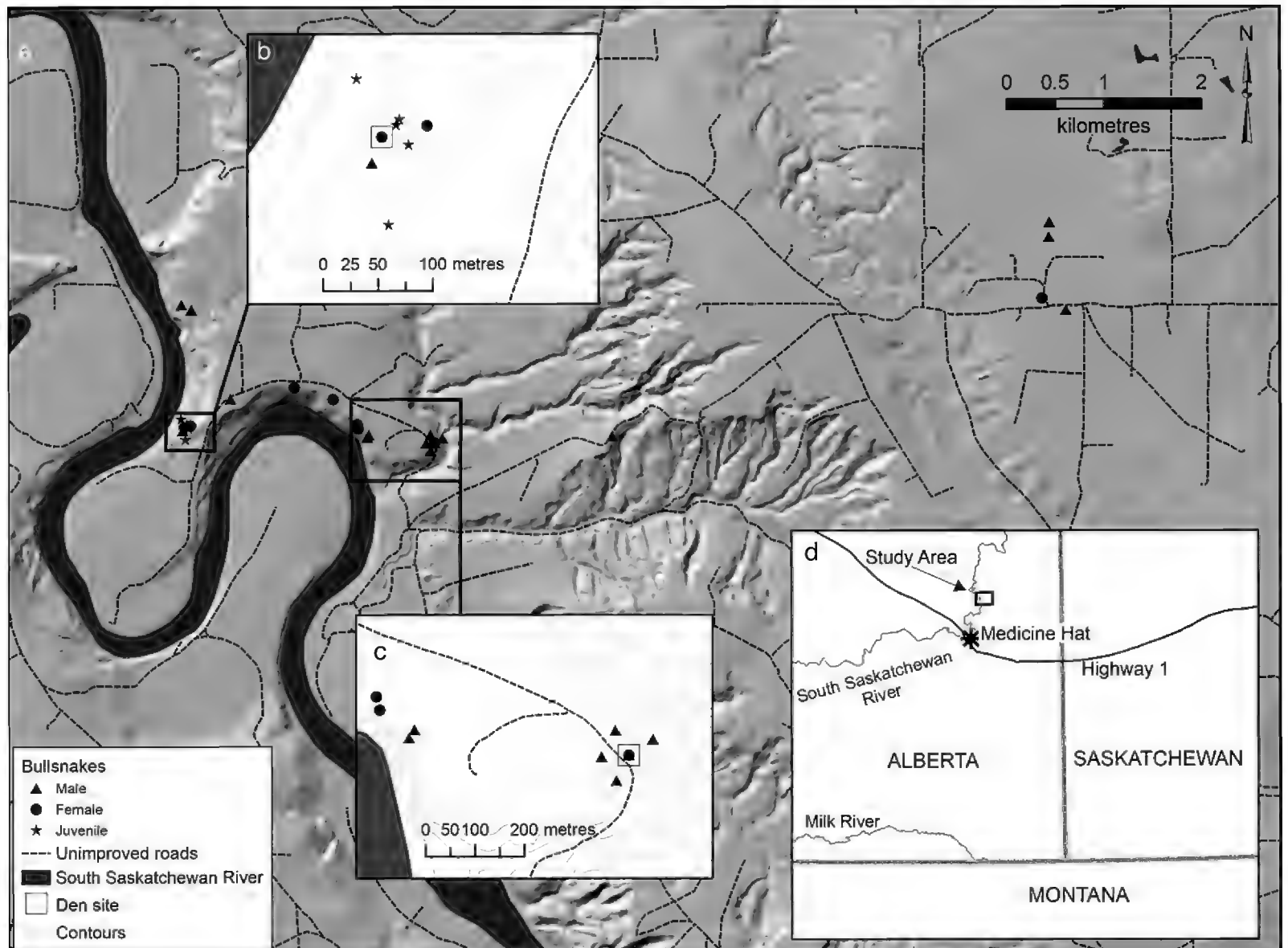


FIGURE 1. a. Relief map of study area and distribution of the 31 Bullsnakes (*Pituophis catenifer sayi*) captured during this study. Some points represent multiple captures. One capture several kilometres to the south is not included. b–c. Framed areas on main map at higher scale. d. Location of the study area.

katchewan River meanders between large alluvial flats and high steep eroding bluffs with abundant slump blocks. The river bank has a mean elevation of 630 m above sea level; elevation to the east reaches 770 m.

The rattlesnake radiotelemetry study covered the territory extending ~15 km to the east of the river, where radio-implanted rattlesnakes were collected and monitored. Tracking the movements of rattlesnakes also took us ~5 km to the south of the fenced hibernacula, which were the geographic central focuses of the study (Figure 1). Most of this area is rangeland, dotted with gas wells and laced by their access roads and pipelines, with limited areas of cultivation immediately to the east of the fenced hibernacula and at the eastern extremity of monitored rattlesnake movement. Although the study area was not pristine at the time of our study, much of it was unmodified and covered with native vegetation.

Within this general area, Bullsnake captures were restricted to a smaller zone at the west end, bounded to the west by the South Saskatchewan River (Figure 1). The general land cover type within this area is mixed grassland, with small patches of agricultural land predominantly to the northeast (Alberta Biodiversity Monitoring Institute 2010).

Methods

Hibernaculum study

Fieldwork was initiated in September 1996. Two hibernacula were identified in the study area. Drift fences and funnel traps were installed in early May 1997 around one of these, which consisted of a series of old Coyote (*Canis latrans*) dens on the upper slopes of a coulee extending east from the river (Figure 1c). All snakes (including Prairie Rattlesnakes and Wandering Garter Snakes [*Thamnophis elegans vagrans*]) that emerged after the fences and traps were set up were captured, processed (see below), and released outside the fences. In the spring and fall of 1997, the immediate area of this hibernaculum (henceforth referred to as the fenced dens) was regularly searched for denning activity and snakes of all species, to a distance of ~1 km north along the east bank of the South Saskatchewan River. All snakes captured in this area (and elsewhere, throughout the study) were processed, and the universal transverse mercator (UTM) locations of the capture points were recorded using a handheld global positioning system receiver: GPS 12 XL (Garmin Ltd., Olathe, Kansas, USA). The traps were reversed in early September 1997, and all captured snakes were released

inside the fences. The fences and traps were removed on 14 October 1997, terminating the 1997 field season.

Snake capture, measurements, and marking

Bullsnakes were captured incidentally while we searched for rattlesnake dens, surveyed our fence and traps, searched for free-roaming rattlesnakes, and radio-tracked eight rattlesnakes. A large amount of terrain was covered on foot, and activities were carried out daily over the entire study period. We captured, or attempted to capture, all Bullsnakes encountered.

All captured snakes were weighed to the nearest gram with a Light Line spring balance (Model No. 10010 – 50 g; and Model No. 42500 – 2500 g; PESOLA Präzisionswaagen AG, Schindellegi, Switzerland). Snout-to-vent length (SVL) and tail length were measured by stretching out the snake against a tape measure laid on the ground. Sex was determined by cloacal probing, although not always with certainty for very young snakes (which were categorized as juveniles and not included in sex-ratio calculations). All snakes of sufficient size (≥ 40 cm SVL) were individually marked with Passive Integrated Transponder (PIT) tags (Anitech TX 1412L, Anitech Enterprises, Inc., Markham, Ontario, Canada), injected dorsally on the left side of the vertebral column ~4 cm ahead of the tail base. Smaller snakes were marked using individual subcaudal scute clip patterns. Recaptures at intervals of more than three weeks were remeasured, as described above. Recaptures of shorter duration were subjected only to PIT tag reading and the collecting of associated environmental data.

At the time of all hand captures, we recorded the temperature (shaded) of the ground, as near as possible to the spot where the snake was resting, UTM coordinates, brief descriptions of weather conditions (including the temperature of the air at 1 m), and the capture situation (activities, if any, and posture) of the snake.

To determine whether adult and juvenile Bullsnakes select different environmental temperatures, we compared mean ground temperatures and mean air temperatures at 1 m for male, female, and juvenile hand captures by means of analysis of variance (ANOVA). To test for possible relations between insolation and surface activity, we cross-tabulated our insolation categories (overcast, sunny, or mixed sun and cloud) and snake capture situation and performed a χ^2 test for random association on the resultant table. All statistical tests were carried out using PAST (Hammer *et al.* 2001). Results of these analyses are provided in Supplemental Material sections S3 and S5.

Mapping

Our GPS data for each hand capture allowed us to examine the distribution of Bullsnakes across the landscape relative to biotic and abiotic characteristics. We used ArcGIS software (version 10.5; Esri, Redlands, California, USA) for visualization and spatial analysis. A shapefile layer of the Bullsnake captures was created

from the recorded GPS coordinates, which were in a UTM zone 12N projection. This layer was overlain on various thematic layers (in shapefile, geodatabase, and Esri grid formats) to determine the following characteristics of the Bullsnake capture locations: topography, generalized land cover, vegetation, and human impact.

Topography was represented by hill shading generated from a digital 10-m resolution elevation model (AltaLIS 2010). Generalized land cover classifications were determined using the Alberta Biodiversity Monitoring Institute's (ABMI 2010) Land Cover Inventory dataset. Site types (landforms/landscape categorization) were determined from the grassland vegetation inventory (Alberta Sustainable Resource Development 2010a,b) and native vegetation from the native prairie vegetation inventory (Alberta Sustainable Resource Development 2004). Human impact factors came from the following sources: agricultural uses from ABMI's (2014) Wall-to-Wall Human Footprint Inventory; roads from the 2016 AltaLIS roads layer; and pipelines and wells from the Alberta Energy Regulator (2017a,b). We superimposed our 1997 Bullsnake distribution data onto two maps (1997 and 2017) depicting gas wells and gas line emplacements, to examine the relationship of Bullsnake habitat use to such features and demonstrate changes in human use of the landscape over this period.

Results

Capture numbers and seasonal distribution

Over the study period, we captured 31 Bullsnakes. Three were recaptured once, and the capture–recapture interval for two was sufficient to require re-measurement. One Bullsnake was recovered from a trap at the fenced dens in the spring (13 May) and six in the fall (6 September to 10 October). Four Bullsnakes were hand captured in the vicinity of dens in the spring and early summer and 10 in the fall (1 September to 3 October). The remaining 10 were encountered while searching for rattlesnakes across the study area. Our adult Bullsnake sample consisted of 16 males and nine females (Table S1), and thus exhibited a proportion of males (males/[males + females]) of 0.64.

Our first capture occurred on 11 May (several Bullsnakes were encountered in the area of the river before this, but were not captured) and our last on 10 October (Figures S1, S2). A gap is evident between 12 June and 19 August (days 163–231) in which only one capture was made, although one dead adult Bullsnake was found on a gas field access road on 2 August.

Hibernacula

Two hibernacula were identified in the study area. The first, the fenced dens, is described above (Figure 1b). The second was located high in an area of slumped terrain immediately above the South Saskatchewan River, facing northeast (Figure 1c). Although other concentrations of Bullsnake captures in similar situations along the course of the river may represent additional overwintering sites, we cannot confidently state that

snakes congregating at them were associating with hibernacula.

Taking the presence of snakes in funnel traps to indicate timing of hibernacula use, egress ended on 13 May and ingress began on 6 September, continuing until 10 October.

Lengths and masses of the snakes

We divided all captured snakes into males, females, and juveniles, i.e., young-of-the-year, sex undetermined (Table S1). The distributions of male and female SVLs overlapped broadly and were discontinuous for both sexes (Figure S3). Males fell into two SVL classes: a small number ranging between 59 and 74 cm and the remainder between 104 and 134 cm. A small number of females were distributed over the 40–60 cm and the 80–90 cm intervals, but most lay within the 110–130 cm interval. Hatchlings were mostly within the 30–40 cm interval of the SVL distribution, although one exceeded 50 cm. The SVL distributions of both males and females overlapped that of hatchlings at their lower ends.

The distributions of male and female masses likewise overlapped broadly (Figure S4). Male masses fell into three groups: 50–150 g, 250–450 g, and 500–750 g. The groups into which female masses fell were more tightly defined: 48–200 g, 400–450 g, and 600–650 g. Juveniles comprised a single mass class, <50 g, which overlapped the lower end of the female mass distribution.

These SVL and mass distributions suggest that Bullsnares at this location fall into clearly defined size categories. Given the small sample size, further division of snake size distributions is unwarranted.

Growth data are available for only two individuals that were captured twice (Table S2), both adult males that fell into the adult male SVL division at first capture. The smaller snake's increase in mass moved it from the subadult mass class to the adult mass class over the capture-recapture period.

Movement

Movement data are available for the two males that were recaptured. The larger of these was captured on 9 June, and recaptured on 2 July (Table S2), moving 96 m nearly due north over this 22-day period. Both capture and recapture were on flat uplands, among the furthest of our captures from the river. The smaller one was captured on 13 May and recaptured on 20 September, moving 375.5 m in a southwest direction over this 130-day interval, from grassland immediately adjacent to a promontory delimited by the river to a slump on the northwest-facing side of this promontory.

Capture situation and insolation

The greatest numbers of hand captures, in the widest range of situations, were made on sunny days or days with mixed sun and cloud. These data are tabulated and the results of a χ^2 analysis for association are given in Table S3.

Environmental temperatures

The distributions of the air and ground temperatures experienced by males, females, and juveniles overlapped broadly (Figure S5).

Distribution over landscape

The great majority of Bullsnares were captured in the immediate vicinity of the South Saskatchewan River, on the bluffs overlooking the channel (Figure 1). One of the two dens identified was near the top of a steep slope forming the upper reaches of the river channel; the other (the fenced dens) lay on the upper reaches of a seasonal channel in close proximity to the river. Only six Bullsnares were captured at any distance from the South Saskatchewan River, two of which were associated with coulees formed by temporary watercourses draining into the South Saskatchewan. Four were located on relatively flat uplands ~7 km from the South Saskatchewan; the distance was calculated from the easternmost meander of the river, as we could not be certain of the den in which these snakes overwintered. Juveniles were restricted to the immediate vicinity of the river. Bullsnares captured at the greatest distance from the river (three males, one female) were all in the adult SVL class.

The area immediately adjacent to the South Saskatchewan River, where most captures were made and both dens were located (Figure 1), is divided between "thin breaks", "limy", and "overflow" site types (Alberta Sustainable Resource Development 2010a,b), covering the steeper slopes of the river channel. Adjacent inland terrain is classified as sand—likely Aeolian or glaciofluvial in this area (Alberta Sustainable Resource Development 2010a,b). Descriptions of these pertinent site types (Alberta Sustainable Resource Development 2010a,b) and numbers of Bullsnares captured in each are provided in Table S4. Bullsnares captured at upland locations were found on margins of tame pasture (two captures), and crop site types (two captures).

Shrub coverage over the study area ranged between the 0–2% and 31–60% class intervals (Alberta Sustainable Resource Development 2004). All Bullsnares captured were made in areas of 0–10% shrub coverage, the majority being within the 3–6% category.

Nesting

We found one Bullsnares nest (1 September) in our study area, located low on the slope of an area of choppy sandhills site type (duned surface of loamy sand and sand soils, with thin vegetation cover; Alberta Sustainable Resource Development 2010a,b), ~2.2 km north by northeast of the northernmost Bullsnares hand capture. The nest had evidently been excavated by a predator of undetermined identity. Some of the eggs had been consumed, leaving only the shells, but, as a single hatchling shed skin was found next to the nest, others had evidently hatched.

Interactions with human landscape modifications

Bullsnakes were generally not associated with human-built structures. Although an unimproved road and a gas pipeline ran along the top of slopes defining the river channel in the area with the greatest density of captures (Figures 1, 2a), snake captures here were almost entirely confined to the slopes themselves. The four captures made away from the river were associated with unimproved roads or areas of modified prairie and were the only ones made in the vicinity of agricultural artifacts. Our two mapped hibernacula were closely associated with buried gas lines, but no Bullsnakes were captured in the vicinity of gas wells (Figure 2a). One Bullsnake was found run over, evidently by a gas field maintenance vehicle, on a gas field access road (not mapped), on 2 August. Two of our hand captures were made on unimproved roads (Table S3).

A marked increase in the density of gas wells and gas lines in the study area has occurred between 1997 and 2017 (Figure 2). The majority of Bullsnake captures in 1997 occurred in areas still untouched in 2017 by gas field development, but much of the terrain east of the South Saskatchewan River has been dissected by such development in the intervening 20 years.

Discussion

The bias in favour of male snakes in our capture sample is similar to that reported elsewhere. For example, the proportion of male adult and juvenile Bullsnakes captured in drift fences during one active season in the adjacent Canadian Forces Base (CFB) Suffield and Suffield National Wildlife Area (Table S2 in Didiuk 2003) was 0.57, which does not differ significantly from our data ($\chi^2_1 = 0.97$, $P = 0.32$). A male bias in Bullsnake captures, and at hatching, has been noted in Nebraska (Gutzke *et al.* 1985; but see Kapfer *et al.* 2008a, for Wisconsin), indicating that the skewed sex ratio in our sample was not a result of intersexual differences in mortality or catchability (Gutzke *et al.* 1985). Also, the lack of significant sexual size dimorphism in our sample (Table S1) has been noted in other parts of the range of this species (Diller and Wallace 1996; Kapfer 2009), although the largest individuals in many populations are males (Kapfer 2009).

The mass and SVL of our juvenile, subadult, and adult Bullsnakes correspond roughly to those of Didiuk (2003). Iverson *et al.* (2008) distinguished a first-year class in their Nebraska Bullsnake sample, but, in that study, body size distribution did not otherwise fall into obvious age or size classes. Bullsnakes in a Wisconsin population were divided among four age-size categories (Kapfer *et al.* 2008a).

The number of Bullsnakes (31) captured over the five months of our study was small compared with the number of Prairie Rattlesnakes (333) captured in the same area over the same period. We recaptured only three Bullsnakes over this period, although 129 of our marked Prairie Rattlesnakes were recaptured at least

once (Powell *et al.* 1998), suggesting that the Bullsnake population is much smaller than the syntopic rattlesnake one. This discrepancy is not reflective of a lack of active sampling effort; suitable habitat for both species was searched frequently over most of the study period, even though rattlesnakes were the desired target of these efforts. The number of Bullsnakes captured in the fenced dens in the fall (11) was also much smaller than the number of rattlesnakes taken at these dens (62). Bullsnakes were observed climbing the fences surrounding these dens, whereas rattlesnakes were not; thus, this capture method may have been unreliable for the former species, although the traps and fence were set up for the greater portion of the period in which snakes were returning to the dens. However, if we assume that the relative numbers of Bullsnakes and Prairie Rattlesnakes captured by passive methods in the fall roughly represent relative population sizes, Bullsnakes are still present in much smaller numbers.

A study of snake movements and numbers in the nearby CFB Suffield and Suffield National Wildlife Area used drift fence arrays set at successively greater distances from the South Saskatchewan River and close to hibernacula in the vicinity of the river (Didiuk 2003). The numbers of Bullsnakes and Prairie Rattlesnakes captured in drift fences over a time span comparable to our study period (395 rattlesnakes, 307 Bullsnakes; Didiuk 2003) did not show the same relative abundance as shown by our data. The habitat in Didiuk's (2003) study area was similar to that in ours. Human presence in the Suffield National Wildlife Area and CFB Suffield is greatly restricted, but gas field activities are conducted in the National Wildlife Area and grazing has been permitted in adjacent areas of the military reserve. Thus, it is unlikely that environmental differences are responsible for the differences in relative numbers of Bullsnakes and Prairie Rattlesnakes between Didiuk's (2003) study and ours.

If Bullsnakes spend the majority of the active season underground (Brown and Parker 1982; Ernst and Ernst 2003; Rodríguez-Robles 2003), walking surveys are likely to miss their presence, whereas the drift fence arrays used by Didiuk (2003) would catch snakes active on the surface, if they were moving significant distances. Our primary method for capturing Bullsnakes away from the vicinities of hibernacula may, thus, have been unsuitable for accruing a representative sample in our study area.

Bullsnake densities appear to be low elsewhere in its range (Fitch 1982; Kapfer *et al.* 2008a). Our findings are consistent with this. Smaller numbers and lower densities in Alberta Bullsnake populations, which are the northernmost of the species' geographical distribution (Russell and Bauer 2000; Ernst and Ernst 2003; Kissner and Nicholson 2003), are to be expected relative to populations further south. Bullsnakes are oviparous (Russell and Bauer 2000; Ernst and Ernst 2003; Kissner and Nicholson 2003; Wright 2008), and the

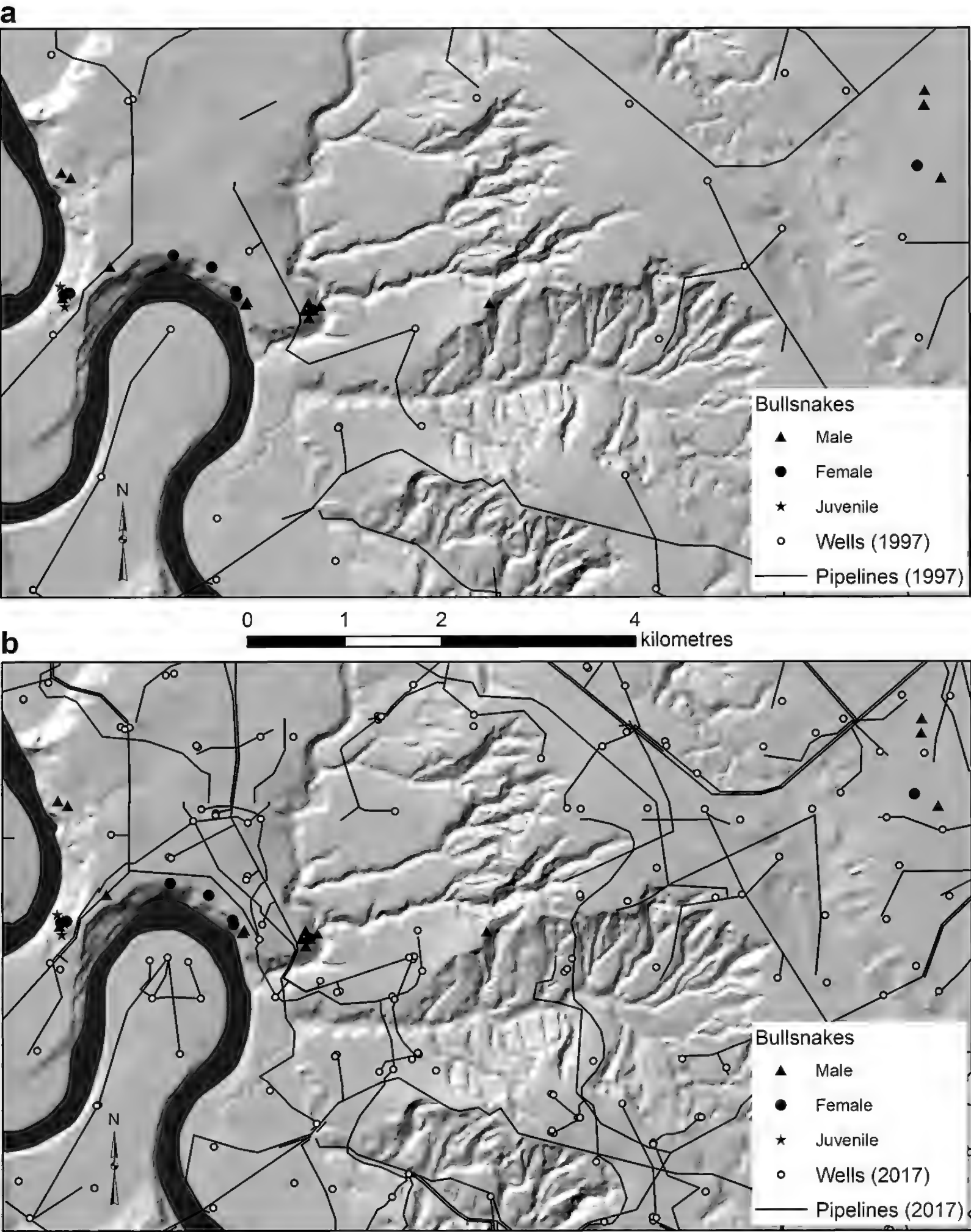


FIGURE 2. a. Study area displaying Bullsnake (*Pituophis catenifer sayi*) captures in relation to gas wells (open circles) and gas pipelines (black lines) in place in 1997. b. Bullsnake captures of 1997 superimposed on map of gas wells and gas pipelines in place in 2017.

success or failure of incubation will depend on seasonal weather conditions and, thus, will potentially vary greatly from year to year at this latitude (Wright 2008). Wright (2008) found that Bullsnares nests in the vicinity of Drumheller, Alberta, were restricted to the microclimatic conditions found in coulees and canyons, a factor that imposes limitations on recruitment.

The seasonal pattern of activity exhibited by Bullsnares in our study (Figures S1 and S2) is consistent with that reported elsewhere (Brown and Parker 1982; Didiuk 2003; Kapfer *et al.* 2008b; Gardiner *et al.* 2013). Our fieldwork did not begin until early May, and our encounters with several individuals before the commencement of data collection indicated that we missed that portion of the Bullsnares population that emerged prior to this (Didiuk 2003; Kissner and Nicholson 2003; Gardiner *et al.* 2013). However, the fencing and open traps around the fenced dens were maintained sufficiently late in the fall that we are confident that our data are indicative of activity during this period. No Bullsnares emerged after mid-May, and return to the fenced dens began on 6 September. Didiuk (2003), at his South Saskatchewan River hibernacula, recorded protracted emergence in spring and dispersal from hibernaculum areas by May, and Bullsnares began appearing in the vicinities of hibernacula in September (Didiuk 2003). For a Utah population of Great Basin Gophersnake (*Pituophis catenifer deserticola*) the timing of spring emergence was more tightly constrained by environmental temperature than that of fall return (Vetas 1951). We have no information on seasonal environmental temperature cues for Alberta Bullsnares populations, but a similar relationship appears likely, as fall returns to the fenced dens took place over a 6-week period, while spring emergence was apparently largely complete early in the active season.

We have posited that the prolonged lacuna in Bullsnares captures in mid- to late-summer (Figures S1 and S2) may be due to a strong tendency toward fossorial activity. Bullsnares have been noted to spend the greater proportion of the active season in burrows (Brown and Parker 1982; Rodríguez-Robles 2002, 2003; Ernst and Ernst 2003). Over their range, they feed preferentially on rodents and other small mammals (Hisaw and Gloyd 1926; Brown and Parker 1982; Fitch 1982; Reynolds and Scott 1982; Cook 1984; Diller and Johnson 1988; Diller and Wallace 1996; Rodríguez-Robles 1998, 2002; Russell and Bauer 2000; Ernst and Ernst 2003; Kissner and Nicholson 2003; COSEWIC 2017). They are accomplished diggers (Carpenter 1982; Sterner *et al.* 2002); Fitch (1982) considered Bullsnares to be specialized for hunting pocket gophers (*Thomomys* spp.) in their tunnels. It is thus possible that many of the Bullsnares in our study area that had dispersed away from the vicinity of the South Saskatchewan River from 12 June to 19 August were actively hunting or lying quiescent underground and were only active on the surface for short periods. Capture situations (Table S3), whether adjacent to the river or elsewhere, would thus repre-

sent surface activity of individuals that had emerged temporarily from their fossorial pursuits. Martino *et al.* (2012) found that the presence of burrows was the best predictor of Bullsnares activity in Grasslands National Park; a minority of our hand captures were made adjacent to burrows or holes (Table S3), but we surveyed only the area in the immediate vicinity of the capture. Thus, this relationship may hold true for our hand captures as well. If summer fossoriality is the rule for Bullsnares, the difference in relative numbers between them and Prairie Rattlesnares may be more apparent than real. Our data do not allow us to test this hypothesis.

Most of our Bullsnares hand captures were made in the vicinity of the river (Figure 1), early and late in the active season (Figures S1 and S2). If our assumption is correct that activity further from the river takes place largely underground, Bullsnares must have moved away from the area adjacent to the river after their period of activity there early in the summer, and moved back late in the summer. Didiuk (2003) recorded most adult Bullsnares captures within 0.2–1 km of the South Saskatchewan River valley rim, but small numbers of captures were made as far as 13.5 km from the river. Bullsnares exhibited strong directionality in spring dispersal away from the river and fall return to it (Didiuk 2003), and individual movements between capture and recapture points could be quite rapid (Didiuk 2003). However, Didiuk (2003) reported Bullsnares captures within 1 km of the river over the entire summer, in contrast to our data (Figures S1 and S2). Gardiner *et al.* (2013) reported that home ranges of Bullsnares in Grasslands National Park, Saskatchewan, exhibited a dumbbell shape—two activity areas (around the hibernaculum and the area of summer activity) separated by a transit corridor, which was traversed quickly in the spring and fall. Our few captures in upland habitat, some 7 km from the easternmost point along the course of the river, are likely of adult snakes that moved this distance (or some fraction thereof). These snakes could represent a portion of the population that moved comparable distances from the river to those of some of Didiuk's (2003) widely-ranging adult Bullsnares, but it does not appear to be a large portion. However, again, the propensity of Bullsnares to spend a great deal of time underground could result in underestimation.

Elsewhere in its distribution, Gophersnake has been shown to overwinter individually, instead of in communal dens shared with other species (Williams *et al.* 2012). This has not been recorded in Alberta, but if some of the Bullsnares from our study did overwinter individually in dens located away from the South Saskatchewan River, they would not be required to make long seasonal dispersals to upland habitat. Further data on Bullsnares movement in Alberta is required to test this possibility.

Martino *et al.* (2012), examining Bullsnares movement in Grasslands National Park, Saskatchewan, found that they travelled 493–3946 m (mean 1709 ± 256 m)

during the active season, with a mean daily movement of 52 ± 7 m. The distances moved by Bullsnares in Grasslands National Park were much smaller than those recorded for Bullsnares denning along the South Saskatchewan River (Didiuk 2003; Martino *et al.* 2012). Evidently Bullsnares exhibit annual movement patterns that accord with local topography, the locations of hibernacula within it, and, presumably, resource availability across it. Studies of Gophersnake home range area and movement elsewhere in the species' geographical distribution (Fitch and Shirer 1971; Rodríguez-Robles 2003; Kapfer *et al.* 2008b) indicate much shorter movements and smaller home ranges than those described for Bullsnares in Alberta (Didiuk 2003) and Saskatchewan (Martino *et al.* 2012; Gardiner *et al.* 2013).

Bullsnake hand captures were generally made close to unimproved roads (Figure 1) and to gas field lines, but never around gas well installations (Figure 2a). Few captures were made in the vicinity of agricultural modifications: installations, equipment, or modified land. Road mortality, particularly resulting from oil and gas field activity, is seen as one of the more pressing threats to Bullsnake populations in Alberta (Didiuk 2003; Kissner and Nicholson 2003; COSEWIC 2017). In the area of Grasslands National Park, Saskatchewan, Bullsnares were found in the vicinity of roads at four times the expected rate for the area occupied by roads (Martino *et al.* 2012). Fortney *et al.* (2012) also found that Bullsnares in Grassland National Park tended to be found on, and close to, roads, this tendency being a function of the proximity of roads to hibernacula and of the type of road (paved, gravel, trail). The area over which our Bullsnake population occurred did not feature any paved roads, and the roads present at that time experienced low levels of traffic. Even so, we recorded one road fatality during our study period, which suggests that road mortality is a constant possibility even here.

Our data were collected in 1997. At that time, gas field installations were relatively few and widely scattered across the area of Bullsnake activity (Figure 2a). In the intervening 21 years, a marked increase in the number of wells and gas lines is evident, both in the vicinity of the hibernacula and across the presumed summer foraging range of the snakes (Figure 2b). This will inevitably have been accompanied by an increase in vehicular traffic and its associated likelihood of Bullsnake road mortality.

The data presented here provide a baseline for numbers and activity of this species across a landscape for which human activity is well-documented, both at present and over two decades ago. This may be useful for future studies of the impact of increased human activity on a Bullsnake population at the northern extremities of its geographic distribution.

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We are pleased to be able to contribute to this tribute to Francis Cook, who has played such a fundamental role in furthering our understanding of the amphibians and reptiles of Canada and in inspiring others to explore the biology of these underappreciated components of this nation's vertebrate fauna. In his iconic book, *Introduction to Canadian Amphibians and Reptiles* (1984, page 175), he states: "Any interested naturalist has an opportunity to make a useful contribution to our knowledge through detailed observations of local habitats... for all species". Our contribution is made in this spirit.

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SUPPLEMENTARY MATERIAL:

SECTION S1. Size of Bullsnares (*Pituophis catenifer sayi*).

SECTION S2. Snout-to-vent length and mass of recaptured Bullsnares (*Pituophis catenifer sayi*).

SECTION S3. Capture situation and insolation during capture of Bullsnares (*Pituophis catenifer sayi*).

SECTION S4. Environmental temperature measured during hand capture of Bullsnares (*Pituophis catenifer sayi*).

SECTION S5. Site types of hand captures of Bullsnares (*Pituophis catenifer sayi*).

TABLE S1. Summary of the lengths and masses of all captured Bullsnares (*Pituophis catenifer sayi*).

TABLE S2. Growth and movement data for the two Bullsnares (*Pituophis catenifer sayi*) recaptured after an interval >3 weeks.

TABLE S3. Cross-tabulation of situation at capture with insolation for all hand-captured Bullsnares (*Pituophis catenifer sayi*).

TABLE S4. Numbers of Bullsnares (*Pituophis catenifer sayi*) hand captured in each site type in the 1997 field season.

FIGURE S1. Distribution of snout-to-vent lengths (SVL) of Bullsnares (*Pituophis catenifer sayi*) captured over the study period, 11 May (day 131) to 10 October (day 283) 1997.

FIGURE S2. Mass of Bullsnares (*Pituophis catenifer sayi*) captured over the study period, 11 May (day 131) to 10 October (day 283) 1997.

FIGURE S3. Distribution of snout-to-vent lengths (SVL) of all Bullsnares (*Pituophis catenifer sayi*) captured over the study period, 11 May to 10 October 1997.

FIGURE S4. Distribution of mass of all Bullsnares (*Pituophis catenifer sayi*) captured over the study period, 11 May to 10 October 1997.

FIGURE S5. Ground (a) and air (b) temperatures for all hand captures of Bullsnares (*Pituophis catenifer sayi*).

Morphology, reproduction, habitat use, and hibernation of Red-bellied Snake (*Storeria occipitomaculata*) near its northern range limit

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Abstract

Northern regions limit ectotherms to relatively short periods of feeding and breeding interrupted by long periods of inactivity. This may force cool-climate ectotherms into different ecological or demographic trade-offs than their southern conspecifics. Our aim is to examine demography, morphology, reproduction, habitat use, and hibernation by populations of Red-bellied Snake (*Storeria occipitomaculata*) near their northern range limit. This research was conducted in southwestern Manitoba and data on summer activity were collected from April to September 2007–2009 using coverboard and pedestrian surveys. Hibernation sites were monitored over three winters (2007–2008, 2008–2009, and 2009–2010), and thermal profiles of *Formica* ant mounds were collected in 2008–2009 and 2009–2010. Females reached sexual maturity at a smaller size than most other populations that have been reported but appear to have similar clutch sizes to the rest of the range. The majority of adult females captured at our summer sites were gravid (96%) suggesting annual reproduction, and activity patterns suggest fall breeding. Near its northern range maxima, this species appears to use relatively warm habitat, have rapid reproduction, and co-opt ant mounds to survive in a difficult climatic environment. Much remains unknown and future studies should further examine the variation in size at maturity and the relationship between body size and clutch size. In addition, little is known about diet, benefits of fall mating, use of open prairie habitats, and late-season migration by *S. occipitomaculata*.

Key words: Red-bellied Snake; *Storeria occipitomaculata*; cool-climate; temperate; Manitoba; thermoregulation; brumation

Introduction

Regions with extended cold seasons present challenges for many ectothermic species, which is reflected by the limited species diversity of snakes and other squamates at higher latitudes (Kiestler 1971). These regions have short summers and long, cold winters that limit individuals to relatively short periods of feeding and breeding interrupted by long periods of forced inactivity (Gregory 2009). Because short active seasons can limit the time available to allocate resources, cold-climate individuals may have different ecological trade-offs than their lower latitude conspecifics (Gregory 2009). As such, aspects of growth (Blouin-Demers *et al.* 2002), reproduction (Gregory 2009), and habitat use (Weatherhead *et al.* 2012) can differ within species across a range, reflecting local selective pressures (Fitch 1981).

Sexual size dimorphism (SSD) has been examined in numerous snake species (reviewed in Shine 1994). Sexual size dimorphism is common but can vary geographically with northern populations. They are often less dimorphic than southern populations which is often attributed to phylogenetic conservatism (Shine 1994; Cox *et al.* 2007). Size at maturity can be conserved across the range of most species, but the age at which an individual reaches mature size may be more plastic (Blouin-Demers *et al.* 2002). Cold-climate reptiles are

expected to grow more slowly and have delayed maturity (Atkinson 1994; Berrigan and Charnov 1994). This is not the case for all species; some populations are able to compensate for shorter growing seasons and have similar or higher reproductive rates compared to southern conspecifics (Tuttle and Gregory 2012, 2014).

The ability of a female to successfully reproduce in any given year is typically dependent on body condition. Most northern reptiles are viviparous with lecithotrophic embryos requiring provisioning predevelopment. The time required to replenish energy stores may delay subsequent reproduction and lead to less than annual reproduction. In some species, yolk is supplemented by limited placental nourishment, allowing gravid snakes some control of provisioning during development (King 1993). In these cases, prolonged gestation would allow for larger or more neonates. This has a cost, as prolonged gestation limits the ability of the mother to feed that, in an already short season, may lead to tradeoffs in energy expenditure not required in less stressful environments.

In high-latitude regions many snakes are not always able to maintain ideal body temperatures, even during the active season (Blouin-Demers and Weatherhead 2001). Reproductive requirements of females also contribute to differences in habitat use and temperature selection between sexes. Thermal requirements to grow

developing embryos may cause females to select different habitats than males and alter their thermoregulatory behaviour (Shine *et al.* 2006). The cold-climate hypothesis predicts that warmer temperatures will be selected by gravid female squamates in cold climates to ensure rapid embryo development (Tinkle and Gibbons 1977). This may lead to increased use of more thermally attractive open or edge habitat than in other parts of a species' range.

Cold-climate reptiles can avoid inclement conditions and limit energy expenditures through hibernation (Gregory 2009). Failure to select appropriate hibernacula leads to death but selecting purely for overwinter survival also has associated costs (Gienger and Beck 2011). Time spent in hibernation subtracts from time spent foraging, therefore hibernacula are often chosen to extend the length of the active season (Gienger and Beck 2011). Features often associated with successful hibernation sites allow for access to soil below the frost line, stability in humidity and temperature, and access to the water table (Harvey and Weatherhead 2006a). The availability of suitable hibernacula is likely the most important form of habitat selection for snakes at high latitudes and may limit the distribution of some species (Harvey and Weatherhead 2006b).

Red-bellied Snake (*Storeria occipitomaculata*) occupies most of eastern North America and is widely distributed in Canada, reaching the northwestern edge of its range in eastern Saskatchewan (Ernst and Ernst 2003). Across its range there have been a number of studies of this species (e.g., Blanchard 1937; Lang 1969; Semlitsch and Moran 1984; Willson and Dorcas 2004; Brown and Phillips 2012) but there has been little research at its northern range limit, with the exception of two natural history observations (Criddle 1937; Gregory 1977). *Storeria occipitomaculata* is a small-bodied, cryptic snake that comes in several ground-shaded dorsal colour morphs and has a bright, reddish-orange ventral surface. They are viviparous, likely with some limited placental provisioning (Blackburn *et al.* 2009). This species, like other members of the genus *Storeria*, feeds primarily on molluscs (Trapido 1944; Brown 1979; Semlitsch and Moran 1984; Pisani and Busby 2011) although not exclusively (Ernst and Ernst 2003). With few species of slugs and snails native to the northwestern edge of its range, local diet remains unknown. This species is considered uncommon to rare throughout much of its range (Ernst and Ernst 2003) but it can be abundant in suitable habitat (Lang 1971). Little is known about population densities for this species, although most studies have recorded low recapture rates (Blanchard 1937; Gregory 1977; Semlitsch and Moran 1984). Typically, *S. occipitomaculata* inhabit thick grassy, herbaceous, and shrubby vegetation, and also can be found in wetlands, riparian areas, and along forest edges and in old field and prairie habitats (Wright and Wright 1957; Cook 1984; Pisani and Busby 2011) as well as drier grasslands habitats (Lang 1969; Brown and Phil-

lips 2012). Criddle (1937) and Lang (1969) both found this species to use abandoned (or nearly so) ant mounds of species of the genus *Formica* as overwintering sites, with the snakes often found hibernating at high densities.

The objective of this study is to examine demography, morphology, reproduction, habitat use, and hibernation in populations of *S. occipitomaculata* near their northern range limit. The stressful environment at high latitudes may force these populations to make trade-offs in their growth, reproduction, and habitat use. We asked the following questions: 1) What are the demographics, morphology, and reproductive traits of this population of *S. occipitomaculata*? and 2) Under what conditions do they hibernate?

Methods

Study sites

Field work in summer habitat use took place in southwestern Manitoba, Canada at the following locations (Figure 1a): Spruce Woods Provincial Park (SWPP; 49.7108°N, 99.2528°W), Assiniboine Corridor Wildlife Management Area (ACWMA; 49.6675°N, 99.5614°W), Oak Lake (49.6644°N, 100.7133°W), and Canadian Forces Base Shilo (CFB Shilo; 49.7381°N, 99.5183°W). A wide variety of habitats were investigated, including agricultural areas, beaver ponds, mixed forest, and mixed-grass prairie. Most sites included water and/or mixed grass prairie. Investigation into hibernation was conducted at the Souris River Bend Wildlife Management Area (SRBWMA; 49.4883°N, 99.8775°W; Figure 1b). Habitat at this area includes mixed forest and grassland, bordered by marsh, agricultural fields, and gravel roads. Details on the habitat types are provided below.

Demography and morphometrics

We recorded the following measurements for all snakes: date, time, snout-vent length (SVL in mm), tail length (mm), head width (mm), head length (mm), mass (g), sex, age, and reproductive condition. We classified all individuals into three age classes: young-of-year (YOY), juvenile, and adult. *Storeria occipitomaculata* were classified into age classes based on their SVL, natal scars, and the minimum breeding SVL of females: YOY (<110mm), juvenile (100–154 mm), and adult (>154 mm). For the age-class analysis we only included the first capture for individuals that were recaptured multiple times within the same season.

To determine reproductive condition, two researchers independently counted enlarged ovarian follicles by palpation (Fitch 1987) and the average of their counts was recorded. All captured individuals were scale-clipped for identification and released at their capture site within 15 minutes of capture. The activity period (27 April to 8 September) was classified by two-week periods numbered 1 through 10. No snakes in this study received more than three clipped ventral scales.

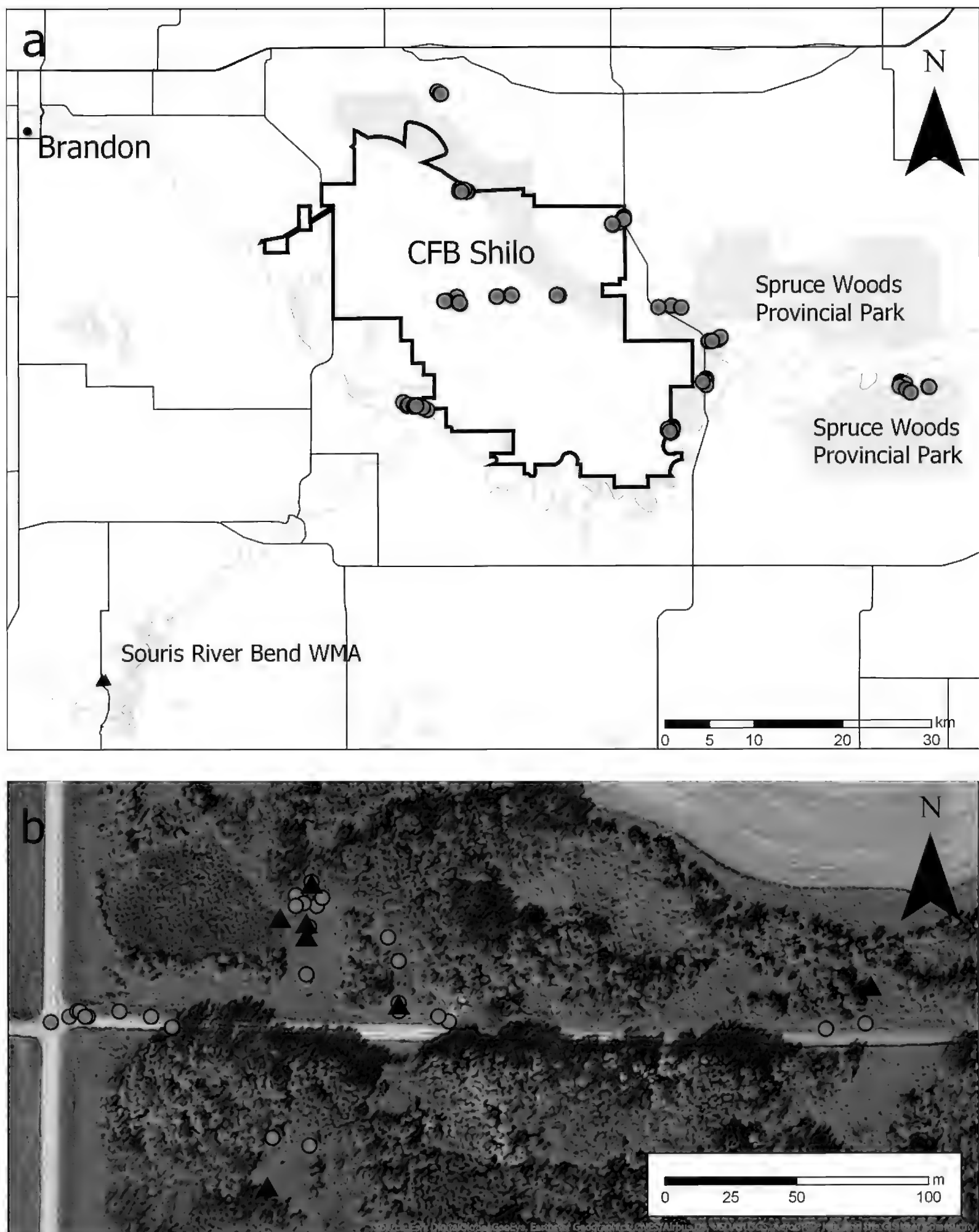


FIGURE 1. a. Map of summer sites (grey circle) and hibernation sites (black triangle) surveyed for Red-bellied Snake (*Storeria occipitomaculata*) 2007–2010 in southwestern Manitoba. b. Map of hibernation study site at Souris River Bend Wildlife Management Area surveyed 2007–2010 showing den sites (black triangle) where traps were set and locations of individual captures (grey circle) outside of the traps. Base map from World Imagery. Accessed 7 October 2018. <https://support.esri.com/en/technical-article/000012040>.

Summer activity

Field sites were surveyed every 2–3 weeks in 2007–2009, from April to September of each year. Surveys were done at various times of day to compare daily habitat usage as the season progressed. We used the same search corridor each time a site was visited to standardize search effort. These routes travelled around or through potentially suitable habitat, often following barriers such as creeks, park paths, or tree lines. Animals were captured by hand as they moved in the open, or when located under cover objects, both natural and artificial (e.g., plywood, sheet metal).

We recorded the following environmental and location data at each capture site: universal transverse mercator coordinates, capture location (in the open or under cover, cover type, and cover thickness), and aspect (0–360°). Collection localities were recorded using a Garmin® GPS60 handheld global positioning system (GPS) receiver (Olathe, Kansas, USA; WAAS enabled accuracy: <3 m, 95% typical). GPS data were used to classify the capture locations according to land cover classes defined by the Manitoba Land Initiative (2012). The following seven classes were used: agriculture, bogs, coniferous forest, deciduous forest, mixedwood forest, grassland, and roads (including trails). Assignments were made using ArcGIS version 10 (ESRI 2011).

Hibernation field data collection

This study took place from September 2007 to June 2010, targetting spring and fall (from 12 April to 5 June in 2008; from 6 May to 2 June in 2009; from 4 April to 20 May in 2010; from 15 September to 4 October in 2007; from 6 September to 25 October in 2008, and 20 September to 4 October in 2009). No traps were used in 2009 (see below for a further description of trapping).

Five abandoned ant mounds were monitored throughout the study (Figure 1b). We replaced two of the mounds that were monitored in 2007 and 2008 with two new mounds in 2008, 2009, and 2010 because the mounds monitored in 2007 and 2008 were destroyed. All ant mounds were ringed with 40 cm tall aluminum flashing. Three openings were cut in the aluminum flashing and a mesh funnel trap made of hardware cloth was placed in each. In fall, two traps were placed on the inside of the flashing at every mound to capture individuals entering the mounds, and one trap was placed on the outside to capture individuals exiting the mounds; the reverse occurred in the spring trapping sessions. Traps were checked every 24–48 h and all individuals were removed from traps. Visual searches were also conducted around the trap sites when traps were checked. All captured individuals were measured (as described above), given a unique scale-clip, and released at the capture site. Individuals caught in traps were released in their direction of travel.

Temperature profiles of the ant mounds were created using iButton® thermal probes (San Jose, California, USA) attached to plastic landscaping rods. iButtons®

were placed in Ziploc® bags and attached to the poles using duct tape. They were deployed over two winters, from 27 September 2007 to 29 May 2008 and 20 September 2008 to 3 June 2009. The iButtons® were set at four distances from the surface: 40, 80, 120, 160 cm in the 2007–2008 hibernation period; and at 0, 40, 80, 120 cm in the 2008–2009 hibernation period. Temperatures were recorded every 3 h. In 2007–2008 all iButtons® deployed at 160 cm below the surface failed because they were below the water table. We did not deploy any iButtons® at this depth in 2008–2009. In 2008–2009, air temperature (1.5 m above the surface) was also recorded.

Statistical analysis

All data analyses were done in R 3.2.1 (R Development Core Team 2017) with $\alpha = 0.05$. We report means, SE, and ranges. Data were log-transformed or nonparametric tests were used, when assumptions of parametric tests were not satisfied. Unless otherwise indicated, adult females include both gravid and non-gravid individuals. Unpaired *t*-tests (package stats; function t.test) were used to compare SVLs within and between sexes, and those captured in the summer versus at the hibernation site (spring and fall). Chi-square analyses (package stats; function chisq.test) were used to compare among categorical variables (see Table 1 for all comparisons). Linear models (package stats; function lm) were used to test for morphological and reproductive relationships (see Table 2 for detailed models). For *P* values between 0.05 and 0.1 power analyses were conducted (package pwr) with reference power = 0.80.

We calculated the mean temperature at each depth for all five dens for each 3 h period within each year. In some cases, we did not have temperatures for all depths at all den sites due to failure of some of the iButtons®. In 2007–2008, one iButton® failed at a den site at both the 80 cm and 120 cm depths. In 2008–2009, one iButton® failed at the 80 cm depth, and three iButtons® failed at the 120 cm depth. Air temperature and surface temperature (0 cm) were only recorded in 2008–2009.

Results

Summer demography, morphometrics, and habitat use

Over the three years we captured 88 individuals (Table S1). Most individuals were adults ($n = 81$; 92%), with only five juveniles and two YOY captured. There was no significant difference in the numbers of captures in each age class (YOY, juvenile, adult) among the three years (Table 1) and no significant difference in the numbers of adult males and females captured among years (Table 1). Adult sex ratios varied during the active season (Table 1; Figure 2) with more males captured in late summer (after 3 August).

Adult female *S. occipitamaculata* tended to be longer (female: 184.2 ± 2.2 mm; male: 175.3 ± 4.0 ; male: female body size = 0.95; $t_{31,3} = 1.94$, $P = 0.06$). Samples were unequal (female: $n = 53$; male: $n = 21$) and power was low (0.50; package pwr; function pwr.t2n.test).

TABLE 1. Chi-square test statistics for comparisons among categories for: summer sites and hibernation sites for Red-bellied Snake (*Storeria occipitomaculata*).

Category	Comparison	χ^2	df	P
SUMMER				
age class (YOY, J, AD)*	year	4.04	4	0.400
adult sex	year	4.02	2	0.130
adult sex	activity (10 periods)	18.44	9	0.030
activity (10 periods)	land-cover use	62.35	27	< 0.001
adult sex	land-cover use	1.34	3	0.720
HIBERNATION				
age class (YOY, J, AD)*	spring versus fall	86.28	2	< 0.001
adult sex	spring versus fall	0.17	1	0.680
species	capture location (trap, mound, road, and grassland)	28.33	9	< 0.001
direction of movement (entering versus exiting)	spring versus fall	0.40	1	0.530

*YOY = young-of-year; J = juvenile; AD = adult.

TABLE 2. Linear models to test for the effects of snout-vent length (SVL) and sex of Red-bellied Snake (*Storeria occipitomaculata*) on tail length, head width, head length, natural log-transformed mass, and number of follicles. Models were done separately for summer sites (S) and the hibernation site (H). The final linear model tests for the effect of year and SVL on the number of follicles in adult females captured at summer sites.

Model	Site type	F	df	P	Adjusted r^2
tail length = sex + SVL + sex × SVL	S	3.95	3,69	0.010	0.11
	H	51.34	3,39	< 0.001	0.78
	sex	6.83	1,69	0.010	
	H	38.54	1,39	< 0.001	
	SVL	3.76	1,69	0.060	
	H	115.28	1,39	< 0.001	
	sex × SVL	1.26	1,69	0.260	
	H	0.20	1,39	0.660	
head width = sex + SVL + sex × SVL	S	4.25	3,69	0.008	0.12
	H	16.18	3,39	< 0.001	0.52
	sex	3.19	1,69	0.080	
	H	1.16	1,39	0.290	
	SVL	8.29	1,69	0.005	
	H	47.35	1,39	< 0.001	
	sex × SVL	1.28	1,69	0.260	
	H	0.01	1,39	0.910	
head length = sex + SVL + sex × SVL	S	9.18	3,62	< 0.001	0.27
	H	16.43	3,26	< 0.001	0.61
	sex	3.02	1,62	0.090	
	H	1.15	1,26	0.290	
	SVL	23.30	1,62	< 0.001	
	H	43.95	1,26	< 0.001	
	sex × SVL	1.21	1,62	0.270	
	H	4.19	1,26	0.050	
log(mass) = sex + SVL + sex × SVL	S	60.12	3,69	< 0.001	0.71
	H	119.20	3,39	< 0.001	0.89
	sex	39.76	1,69	< 0.001	
	H	2.25	1,39	0.140	
	SVL	140.16	1,69	< 0.001	
	H	350.32	1,39	< 0.001	
	sex × SVL	0.45	1,69	0.500	
	H	5.15	1,39	0.030	
no. follicles = year + SVL + year × SVL	S	9.53	5,68	< 0.001	0.38
	year	11.80	2,33	< 0.001	
	SVL	22.61	1,33	0.040	
	year × SVL	0.12	2,33	0.890	

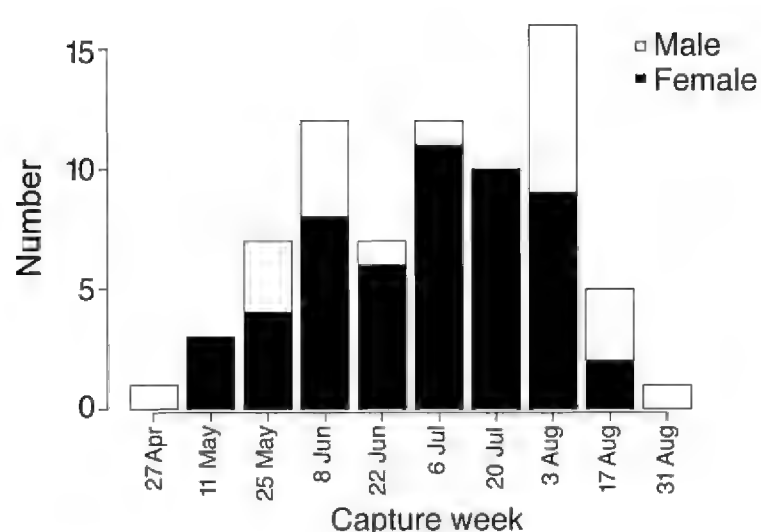


FIGURE 2. Numbers of adult male and female Red-bellied Snake (*Storeria occipitomaculata*) captured during summer surveys 2007–2009 at Spruce Woods Provincial Park (SWPP), Assiniboine Corridor Wildlife Management Area (ACWMA), Oak Lake, and Canadian Forces Base Shilo (CFB Shilo). The season was divided into ten, two-week periods and the capture week indicates the start of the two-week period.

Sample sizes of 60 in each group would have detected a significant difference ($\alpha < 0.05$) with power = 0.80. Males had significantly longer tails than females (Table 2; Figure 3a). Males tended to have wider and longer heads (Table 2). Females were significantly heavier than males (Table 2; Figure 3b).

The majority of adult females captured were gravid ($n = 46$; 96%). Enlarged follicles were detected from 14 May to 11 August. Gravid females had 4–12 follicles (modes = 5, 6, 7, and 10, median = 7). The number of follicles increased with SVL (Table 2; Figure 4) and was significantly different among the three years (2007: modes = 0, 4, and 7, median = 6; 2008: mode = 6, median = 6; 2009: mode = 10, median = 9; Table 2; Figure 4).

Individuals were most commonly found in grassland habitat ($n = 51$; 59%), followed by deciduous forest ($n = 22$; 25%), roads ($n = 9$; 10%), and mixedwood forest ($n = 5$; 6%). Land-cover use differed across the 10, two week periods (Table 1; Figure 5). Mixedwood forest

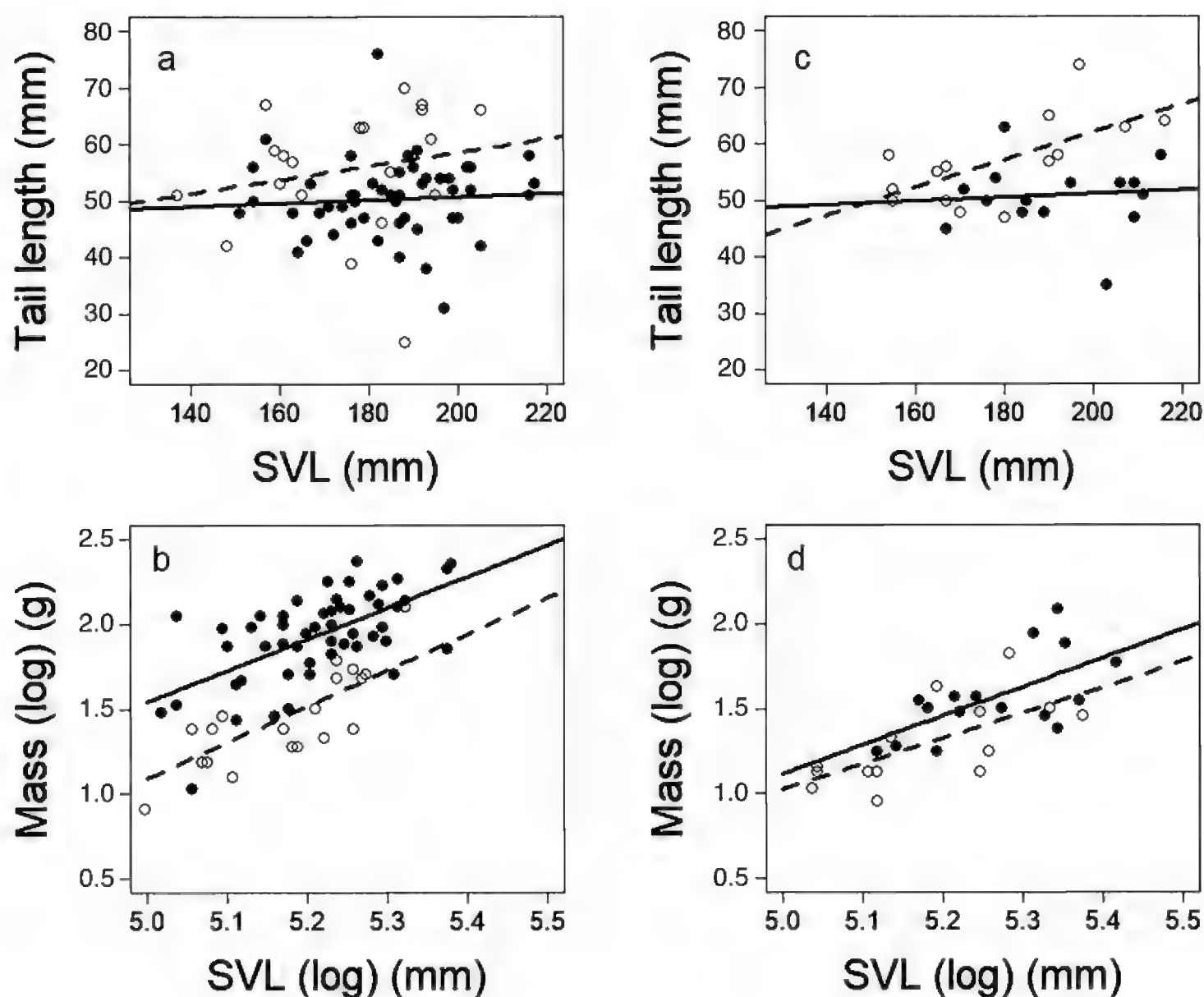


FIGURE 3. a. Snout-vent length (SVL) versus tail length, and b. natural log-transformed SVL versus natural log-transformed mass for adult male (open circle, dashed line) and female (filled circle, solid line) Red-bellied Snake (*Storeria occipitomaculata*) captured during summer surveys 2007–2009 at Spruce Woods Provincial Park (SWPP), Assiniboine Corridor Wildlife Management Area (ACWMA), Oak Lake, and Canadian Forces Base Shilo (CFB Shilo). c. SVL versus tail length, and d. natural log-transformed SVL versus natural log-transformed mass for adult male (open circle, dashed line) and female (filled circle, solid line) *S. occipitomaculata* captured during spring and fall surveys 2007–2010 at the hibernation site (Souris River Bend Wildlife Management Area).

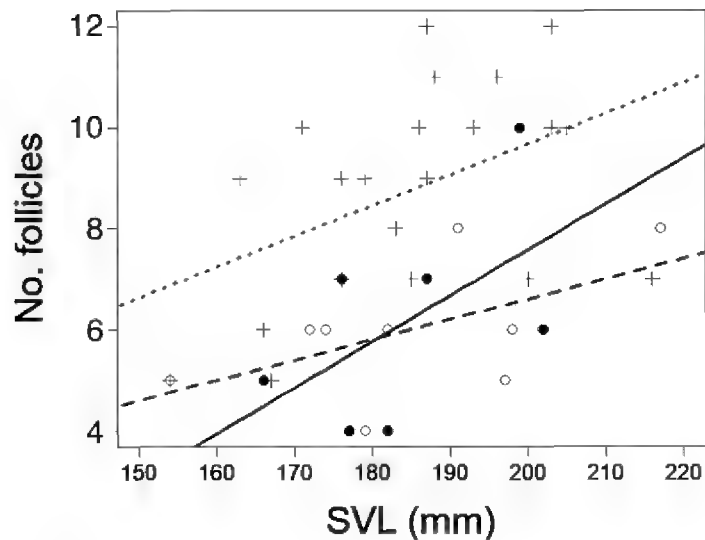


FIGURE 4. Snout-vent length (SVL) versus number of follicles for adult gravid female Red-bellied Snake (*Storeria occipitomaculata*) captured during summer surveys 2007–2009 at Spruce Woods Provincial Park (SWPP), Assiniboine Corridor Wildlife Management Area (ACWMA), Oak Lake, and Canadian Forces Base Shilo (CFB Shilo). Linear regressions are shown separately for each year: 2007 (open circle, dashed line), 2008 (filled circle, solid line), and 2009 (cross, dotted line).

was used in spring (11 May to 15 June), while roads and grassland were most commonly used in late summer (3–10 August). There was no difference in land-cover use of males and females (Table 1).

Approximately a third of captures were on flat ground ($n = 23$; 30%). Individuals that were captured on slopes were captured on slopes with a mean aspect of $18.2 \pm 1.04^\circ$ (south facing). Most captures were under cover ($n = 73$; 87%). Preferred cover types were: plywood ($n = 41$; 56%), natural log ($n = 9$; 12%), railway tie ($n = 8$; 11%), plank ($n = 6$; 8%), and other ($n = 9$; 13%). Mean cover thickness was 36.5 ± 5.2 mm (range = 1–220 mm, median = 19 mm). Sampling effort for slope and cover types was not quantified. Therefore, the above values do not necessarily reflect habitat selection, and may simply reflect a bias in availability.

Hibernation demography, morphometrics, and habitat use

At the hibernation site (SRBWMA) we found 57 individuals representing all three age classes for *S. occipitomaculata*. Adults were the most common ($n = 35$; 61%), followed by similar percentages of juveniles ($n = 12$; 21%) and YOY ($n = 10$; 18%). There was a significant difference in the numbers caught by age class (YOY, juvenile, adult) between spring and fall (Table 1). In the fall there were more adults ($n = 25$; 71% of all adults) and YOY ($n = 10$; 100% of all YOY) captured, and more juveniles captured in the spring ($n = 11$; 89% of all juveniles). There was no significant difference in the numbers of males and females captured in the spring versus the fall (Table 1). Adult female *S. occipitomaculata* captured at the hibernation site were significantly larger than males (193.9 ± 4.4 mm and 178.9 ± 5.4 mm respectively; $t_{26,1} = 2.17$, $P = 0.04$). Males had significantly longer tails than females

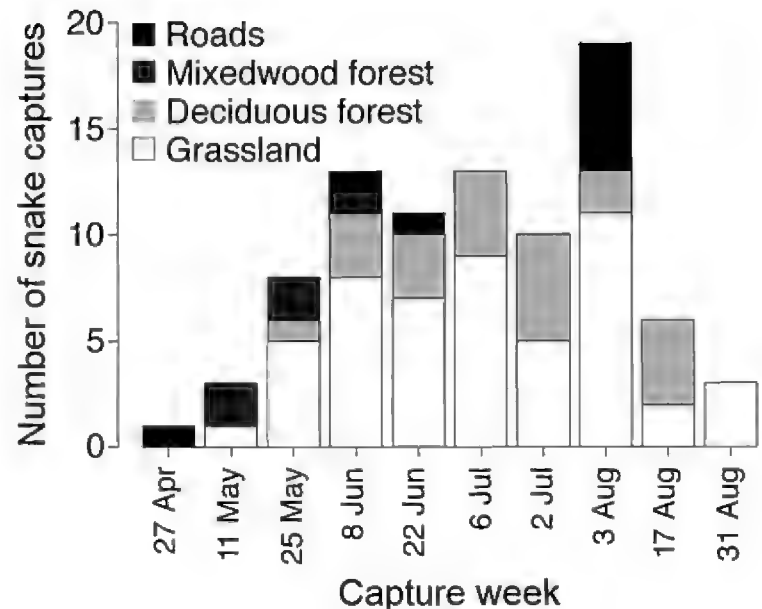


FIGURE 5. Habitat use of Red-bellied Snake (*Storeria occipitomaculata*) captured during summer surveys 2007–2009 at Spruce Woods Provincial Park (SWPP), Assiniboine Corridor Wildlife Management Area (ACWMA), Oak Lake, and Canadian Forces Base Shilo (CFB Shilo). The season was divided into ten two-week periods and the capture week indicates the start of the two-week period.

(Table 2; Figure 3c). There was no difference between head widths (Table 2) or head lengths of males and females (Table 2). There was no difference in mass between males and females (Table 2; Figure 3d).

Storeria occipitomaculata shared the hibernation site with three other species of snakes: Plains Garter Snake (*Thamnophis radix*), Red-sided Garter Snake (*T. sirtalis parietalis*), and Smooth Greensnake (*Opheodrys vernalis*) that used both the surrounding area and den sites. Over three years we captured 166 individuals (Table 3). Most were found during fall surveys ($n = 114$; 69%). Trapping percentages were highest in *O. vernalis* and *T. radix* (Table 4). Individuals were first captured in traps on 16 September 2007, 13 September 2008, and 23 September 2009. Timing of the first spring captures in traps was more variable: 7 May 2009 and 9 April 2010. More individuals were captured during our visual searches, either in the grassland ($n = 50$; 30%), on the road ($n = 28$; 17%), or inside aluminum flashing on ant mounds ($n = 13$; 8%). The remaining individuals ($n = 75$; 45%) were captured inside traps. There were significant differences among the four species in capture sites (Table 1). *Storeria occipitomaculata* and *O. vernalis* were captured significantly more often on roads than *Thamnophis* spp. Most snakes found in the grassland were *T. sirtalis parietalis*, and there were no *O. vernalis* found in this habitat. Most snakes found on ant mounds were *Thamnophis* spp.

There was no significant difference in direction of movement (entering or exiting the ant mound) in fall as compared to spring (Table 1). Few *S. occipitomaculata*, *T. radix*, and *T. sirtalis parietalis* were recaptured within the same season (11% in total; Table S2). There were only three individuals (2%; all *Thamnophis* spp.) recaptured between seasons; one of these individuals had

TABLE 3. Numbers of each species captured in different capture locations (trap, ant mound, road, or grassland) at the Souris River Bend Wildlife Management Area study site 2007–2010. Percentages within each category are indicated in brackets. Species are: Smooth Greensnake (*Opheodrys vernalis*), Northern Red-bellied Snake (*Storeria occipitomaculata*), Plains Garter Snake (*Thamnophis radix*), and Red-sided Garter Snake (*Thamnophis sirtalis parietalis*). Only visual searches were conducted in fall 2009.

Year, season	Capture location	Smooth Greensnake	Northern Red-bellied Snake	Plains Garter Snake	Red-sided Garter Snake	Total
2007, fall	Trap	0	16	4	2	22 (71)
	Mound	0	0	1	4	5 (16)
	Road	1	1	0	0	2 (6)
	Grassland	0	1	1	0	2 (6)
	Total	1	18	6	6	31
2008, spring	Trap	1	0	1	0	2 (50)
	Mound	0	0	0	0	0
	Road	0	0	0	0	0
	Grassland	0	0	1	1	2 (50)
	Total	1	0	2	1	4
2008, fall	Trap	4	4	5	24	37 (46)
	Mound	1	1	0	5	7 (9)
	Road	1	16	1	3	21 (27)
	Grassland	0	1	1	12	14 (18)
	Total	6	22	7	44	79
2009, spring	Trap	0	3	0	0	3 (13)
	Mound	0	0	0	0	0
	Road	0	2	1	0	3 (13)
	Grassland	0	4	1	13	18 (75)
	Total	0	9	2	13	24
2009, fall	Road	1	1	0	0	2 (50)
	Grassland	0	2	0	0	2 (50)
	Total	1	3	0	0	4
2010, spring	Trap	2	4	2	3	11 (46)
	Mound	0	0	1	0	1 (4)
	Road	0	0	0	0	0
	Grassland	0	8	1	3	12 (50)
	Total	2	12	4	6	24
Total	Trap	7 (64)	27 (42)	12 (57)	29 (41)	75 (45)
	Mound	1 (9)	1 (2)	2 (10)	9 (13)	13 (8)
	Road	3 (27)	20 (31)	2 (10)	3 (4)	28 (17)
	Grassland	0	16 (25)	5 (24)	29 (41)	50 (30)
	Total	11 (7)	64 (39)	21 (13)	70 (42)	166

also been recaptured within a season. No *O. vernalis* were recaptured. Few individuals were found dead on the road (3%) or dead in a trap or within the aluminum flashing (3%). When individuals were recaptured within the season, they were most frequently first captured in a trap entering the ant mound and secondly captured in a trap exiting the ant mound ($n = 11$; 61%). All other recaptures (first capture/second capture) were grassland/road (*T. sirtalis parietalis*; $n = 2$), grassland/grassland (*T. sirtalis parietalis*; $n = 2$), road/road (*S. occipitomaculata*; $n = 1$), mound/grassland (*T. sirtalis parietalis*; $n = 1$), and mound/mound (*T. sirtalis parietalis*; $n = 1$). A single *T. sirtalis parietalis* was recaptured, both times in a trap that exited the mound.

Thermal profiles of den sites

Air temperature and surface temperature (0 cm) were highly variable, and both stayed below freezing from 1 November to 1 March (Figure 6). Temperatures at a depth of 40 cm were more stable but were below freez-

ing from 1 December to 1 April. Temperatures at a depth of 80 cm and 120 cm below the surface were also stable but largely stayed above freezing. In 2007–2008, the temperature at the 80 cm depth dipped to minus 0.1°C in February but stayed above freezing in 2008–2009.

Summer versus hibernation morphometrics

Adult females tended to be larger at the hibernation site than at summer sites (hibernation: 193.9 ± 4.4 mm; summer: 184.2 ± 2.2 mm; $t_{23,3} = 1.99$, $P = 0.06$). Sample sizes were unequal (summer: $n = 53$; hibernation: $n = 17$), and power was low (0.54; package pwr; function pwr.t2n.test). Sample sizes of 47 in each group would have detected a significant difference ($\alpha < 0.05$) with power = 0.80. There was no significant difference in SVL of adult males captured at the hibernation site compared to the summer sites (hibernation: 178.9 ± 5.4 mm; summer: 175.3 ± 4.0 mm respectively; $t_{26,2} = 0.55$, $P = 0.59$). For adult females, there was no sig-

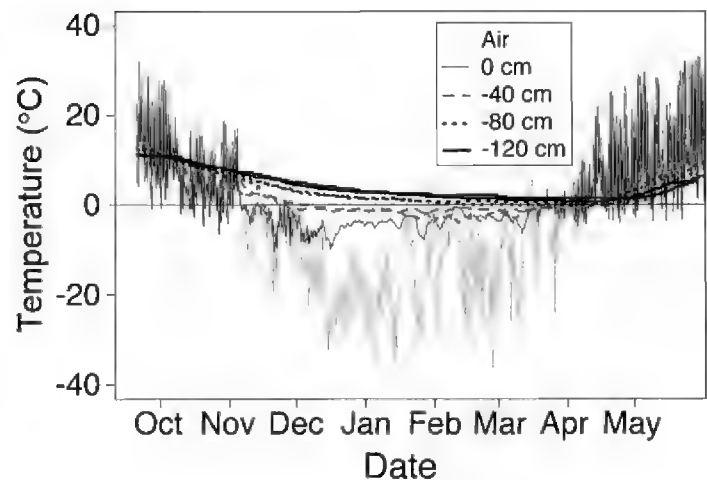


FIGURE 6. Mean temperatures from iButtons® placed at five den sites at Souris River Bend Wildlife Management Area over winter (20 September–22 May) in 2007–2008 and 2008–2009. Separate lines are shown for each winter; air temperature and surface temperature (0 cm) were only recorded in 2008–2009.

nificant difference in tail or head length (Table 4) for individuals captured at the hibernation site compared to those captured at summer sites. Adult females at the hibernation site had wider heads than those from summer sites (Table 4). For adult males, there was no significant difference in tail length, head width, or head length (Table 4) for individuals captured at the hibernation site compared to those captured at summer sites. Both adult females (Table 4; Figure 3b) and adult males (Table 4; Figure 3d) were significantly heavier for their body size at summer sites compared to the hibernation site.

Discussion

Our study examined demography, morphology, reproduction, habitat use, and hibernation in populations of *S. occipitomaculata* in southwestern Manitoba. This area is relatively arid and has an average daily temperature across the year of only 2.2°C (Environment Canada 2016). This is a stressful environment, but the explosive productivity of summer may be enough to compensate (Tuttle and Gregory 2014). Variation between populations we observed and other parts of this species’ range may indicate how they make up for this stress.

The demographics of *S. occipitomaculata* were similar to the findings of Blanchard (1937) with adults accounting for the vast majority of observations. We suspect this may simply reflect the difficulty of finding juveniles using walking surveys. When using funnel traps at hibernation sites we collected more YOY and juveniles. However, Semlitsch and Moran (1984) also observed adult biased demographics using passive trapping.

Although we observed female biased SSD in this population, differences were not large. Male to female body size ratios were similar to populations from Michigan, Minnesota, and interestingly South Carolina, but less dimorphic than populations in Virginia, Indiana, or Pennsylvania (reviewed in Meshaka and Klippel 2011). Body sizes at our study sites were smaller than most other locales, including other northern populations (Criddle 1937; Meshaka and Klippel 2011). The minimum size of gravid snakes in our study was 154 mm,

TABLE 4. Linear models comparing tail length, head width, head length, and natural log-transformed mass of Red-bellied Snake (*Storeria occipitomaculata*) between summer and hibernation sites (site variable). Models were done separately for each sex. SVL = snout-vent length.

Model	Sex	F	df	P	Adjusted r ²
tail length = site + SVL	F	0.24	2,64	0.790	0.02
		0.15	1,64	0.700	
		0.58	1,64	0.570	
	M	2.13	2,31	0.140	0.06
		0.19	1,31	0.670	
		4.08	1,31	0.050	
head width = site + SVL	F	2.49	2,64	0.090	0.04
		4.61	1,64	0.040	
		0.37	1,64	0.550	
	M	7.12	2,31	0.003	0.27
		0.51	1,31	0.480	
		13.72	1,31	< 0.001	
head length = site + SVL	F	5.80	2,54	0.005	0.15
		0.08	1,54	0.780	
		11.52	1,54	0.001	
	M	3.78	2,25	0.040	0.17
		0.04	1,25	0.840	
		7.5	1,25	0.010	
log(mass) = site + SVL	F	36.61	2,64	< 0.001	0.52
		36.77	1,64	< 0.001	
		36.46	1,64	< 0.001	
	M	21.58	2,31	< 0.001	0.56
		4.50	1,31	0.040	
		38.66	1,31	< 0.001	

larger than those in South Carolina (Semlitsch and Moran 1984) and similar to Virginia (Mitchell 1994), but smaller than most of the rest of the range (Meshaka and Klippel 2011). The literature suggests, while body size in *S. occipitomaculata* varies, average clutch sizes are similar across its range. In our study, gravid females had similar clutch sizes to other populations (7–9 young; Meshaka and Klippel 2011). Northern reptiles are often thought to be constrained, having slower growth and delayed maturity relative to southern populations (Atkinson 1994) but this is not always the case (Angilletta *et al.* 2004; Tuttle and Gregory 2012, 2014). Early maturity is usually accomplished by increased growth to similar minimum size (Tuttle and Gregory 2012, 2014). *Storeria occipitomaculata* appears to mature at a smaller size in the southeast and northwest portions of its range while maintaining similar clutch sizes to physically larger populations elsewhere.

Although spring breeding has been widely reported in this species (Semlitsch and Moran 1984; Ernst and Ernst 2003; Meshaka and Klippel 2011) the abundance of males in late summer suggests August breeding activity (Blanchard 1937; Trapido 1940; Willson and Dorcas 2004). Although we did not directly observe any fall mating, it has been reported previously in Manitoba (Gregory 1977). Also, we found evidence of primary vitellogenesis pre-hibernation in two road-killed specimens collected in October 2007 and captured gravid females as early as 14 May. In our study, the majority of adult females captured during the summer were gravid (96%) suggesting annual reproduction similar to populations in the south (Semlitsch and Moran 1984). Reproduction should be limited by available resources (Aldridge 1979) and biennial reproduction appears to be common in northern snakes (Larsen *et al.* 1993; Gregory 2009). Mating in late summer/fall would provide females with a longer foraging and gestation period that would allow for greater provisioning of offspring *in utero* and may explain this population's ability to reproduce annually despite the short season. This is likely an important life history trait for a short lived species like *S. occipitomaculata* (Snider and Bowler 1992).

The habitat use by *S. occipitomaculata* we observed in Manitoba was similar to that found in Minnesota (Lang 1971) and Illinois (Brown and Phillips 2012) but differed from findings in Kansas (Pisani and Busby 2011). We found disproportionate use of grassland habitat on flat land or with south facing aspects. Pisani and Busby (2011) found the majority of their sample associated with moister habitats avoiding open habitats on north, west, and east slopes, and usually associated with water. These differences may reflect local availability, local adaptation, or perhaps a trade-off made by northern *S. occipitomaculata*, sacrificing osmotic preferences for thermal ones. This may be compensated for by microhabitat selection. In our study, most captures were under cover (87%) and more than half were found under plywood. This pattern may reflect our sampling

methods rather than true preferences, although a preference for cover objects is common in small snakes (Halliday and Blouin-Demers 2015; Gregory and Tuttle 2016).

Land-cover use differed across the 10, two week periods of our study. Use of mixedwood forest by *S. occipitomaculata* occurred in spring, while they used roads and grassland most commonly in late summer and fall (at the hibernation site). Semlitsch and Moran (1984) suggested that moisture gradients and food availability drove activity pulses and habitat choice in this species in South Carolina. Alternatively, use of grasslands in late summer may reflect habitat preferences of gravid females, because grasslands are warmer than forest habitats in keeping with the cold climate hypothesis (Tinkle and Gibbons 1977) although we did not observe a sex bias in habitat choice.

Over the course of three years, the first arrival of *S. occipitomaculata* at hibernation sites was later than other species and was consistently associated with the first frost or nighttime temperatures below freezing similar to Lang (1971). In cold regions such as Minnesota or Manitoba, it is difficult to understand why a small snake would arrive at a hibernaculum so late in the season when hard frosts are likely. Although *S. occipitomaculata* appears to be able to cope with several days of cold weather, a prolonged or particularly hard frost may cause mortality (Lang 1971). Critical thermal minimum (CT_{min}) has not been determined in *S. occipitomaculata* but ranges from 2.5 to 11.5°C in other snake species with body size, species, and latitudinal effects (reviewed in Cox *et al.* 2018) so it likely above 0°C. In the smaller Ring-necked Snake (*Diadophis punctatus*) CT_{min} was 11.5°C and decreased with increasing body size, suggesting that small individuals require higher CT_{min} (Cox *et al.* 2018).

The use of ant mounds by *S. occipitomaculata*, *O. vernalis*, and *T. sirtalis parietalis* has been previously reported by Criddle (1937), Carpenter (1953), Lang (1971), and Pisani (2009). These mounds do not offer a thermal advantage over the winter compared to surrounding soil (Scherba 1962). However, due to their insulation and ability to collect solar radiation, these sites are warmer and more stable during the active season (Scherba 1962; Duff *et al.* 2016), thereby potentially increasing season length. The thermal profiles we generated at the hibernation site indicated stability increases with soil depth but, even at 80 cm, temperatures dipped below freezing. This is similar to the temperature profile generated by Lang (1971), although the frost lines at most of the ant mounds he investigated were slightly deeper, likely due to the shallow water table at our hibernation site. The temperature profile of the mounds suggests that these snakes would have to hibernate near or below the water table (Costanzo 1989) which was ~120 cm in our study. Criddle (1937) found this to be the case when he excavated a mound near Treesbank, Manitoba and found many of the snakes

at ~144 cm depth, in contact with the water table. Without these abandoned ant mounds *S. occipitomaculata*, poorly suited to true burrowing with its kinetic skull and large eyes, would be unable to access such thermally stable and humid refuges (Pisani 2009). These sites, or other similar fossorial retreats, are likely critical for the persistence of this species at such northern climates.

Caution must be taken when comparing snapshots of populations' life histories (Seigel and Fitch 1985). There is a great deal of variation reported across the species' range and among individuals, and like Meshaka and Klippel (2011), we found a limited effect of latitude between the population we observed and the rest of the range. This observation adds to our understanding of how this species can survive in an area that is climatically unsuitable for terrestrial activity for much of the year. In this area, this species appears to use relatively warm habitats, rapid reproduction, and abandoned ant nests to persist and thrive. Productive habitats, such as the northern Great Plains, may allow this species to adopt a "fast" lifestyle that favours early maturity and higher than expected annual fecundity, with most females reproducing annually (Tuttle and Gregory 2014). Much remains unknown and future studies should confirm the genetic or environmental underpinning of body size at maturity and clutch size along with local diet, timing of breeding, and the drivers and risks associated with late-season migration for this species.

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SUPPLEMENTARY MATERIAL:

TABLE S1. Numbers of Red-bellied Snake (*Storeria occipitomaculata*) in three age classes (young-of-year [YOY], juvenile, adult) for each sex that were captured during summer surveys 2007–2009 at Spruce Woods Provincial Park (SWPP), Assiniboine Corridor Wildlife Management Area (ACWMA), Oak Lake, and Canadian Forces Base (CFB) Shilo.

TABLE S2. Number of captures, recaptures, and dead animals for individuals captured at the hibernation site (Souris River Bend Wildlife Management Area) during spring and fall surveys 2007–2010.

Spring Peeper (*Pseudacris crucifer*) in Labrador, Canada: an update

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Abstract

Spring Peeper (*Pseudacris crucifer*) was first confirmed in Labrador in 1998, when vocalizations were recorded near Happy Valley-Goose Bay. Prior to this, only unsubstantiated reports of Spring Peepers in Labrador existed. In 2006, we visually documented nine Spring Peepers at six locations west of Happy Valley-Goose Bay, in the lower Churchill River valley. In 2014, using auditory surveys, we further documented 1–10 Spring Peepers calling at 13 additional locations in the same general area. These new records support earlier findings and provide additional information on the species at the extreme northeastern edge of its range.

Key words: Amphibian; Spring Peeper; *Pseudacris crucifer*; range; Labrador

Introduction

Bleakney (1954) reported that a student described watching “tiny tree frogs with suction disc finger tips and huge vocal sacs” in a ditch near Menihék Lake Camp in western Labrador, suggesting that the frogs in question were Spring Peepers (*Pseudacris crucifer*). Maunder (1983) subsequently reported that two environmental personnel working in Labrador heard what they believed to be at least one Spring Peeper calling on the evening of 11 July 1980 near Thomas Brook (53.17°N, 60.93°W) in the lower Churchill River Valley.

However, the first tangible evidence for Spring Peepers in Labrador was provided by Bergman (1999). In her account, Bergman described hearing infrequent calls of single Spring Peepers throughout the day on 14 June 1998 while canoeing on the Peters and Goose Rivers (between 53.33°N, 60.78°W and 53.40°N, 60.43°W), as well as a large chorus of Spring Peepers that same evening adjacent to the Goose River (53.38°N, 60.48°W). The following evening, she made an audio recording of two Spring Peepers calling in a small marsh on the south bank of the Goose River (53.37°N, 60.50°W). This recording is vouchered in the natural history collection of The Rooms Provincial Museum in St. John’s, Newfoundland (NFM HE-122). In an addendum to her publication, Bergman indicated that she had been informed that school children had observed “weensy tree frogs” with “sticky feet” that were consistent in colour with Spring Peepers, in the trees and bushes near Gosling and Alexander Lakes, near Happy Valley-Goose Bay.

Since Bergman’s (1999) publication, there have been no additional peer-reviewed, published records of the species in Labrador. However, in 2006, a series of field-based studies was initiated in support of an environ-

mental assessment of the Lower Churchill Hydroelectric Generation Project. As part of these studies, we documented Spring Peepers and other amphibians along the north and south sides of the lower Churchill River Valley in central Labrador.

Methods

Our study area focussed on the segment of the lower Churchill River Valley between Horse Island Rapids (52.9965°N, 61.5323°W) and Muskrat Falls (53.2247°N, 60.8640°W; Figure 1), in the vicinity of the abovementioned hydroelectric project. Specifically, we surveyed natural habitats within 2 km of the river and its tributaries, primarily in road accessible areas. Note: on completion of the hydroelectric project, the projected reservoir-related flooding will not inundate much of the area we surveyed (see Figure 2-1 and Figure A-1 in Stassinu Stantec 2014).

Ground surveys to locate and identify amphibians occurred 13–15 July 2006 in 27 locations in our study area, as well as in areas along the Goose River and Lake Winokapau (Minaskuat Inc. 2008a). To supplement these efforts, observations of amphibians were collected during five other field programs targetting other components (e.g., wetland and rare plant surveys), but inclusive of suitable habitat for amphibians. Combined, these surveys spanned a period from 24 June to 14 September 2006 and involved visits to >400 locations over 75 field days (Minaskuat Inc. 2008b,c,d,e,f). All surveys were conducted by groups of 2–4 people (with at least one wildlife biologist per group) operating per field day. Groups walked through wetlands and forested habitats as they were encountered and documented all amphibians heard or observed.

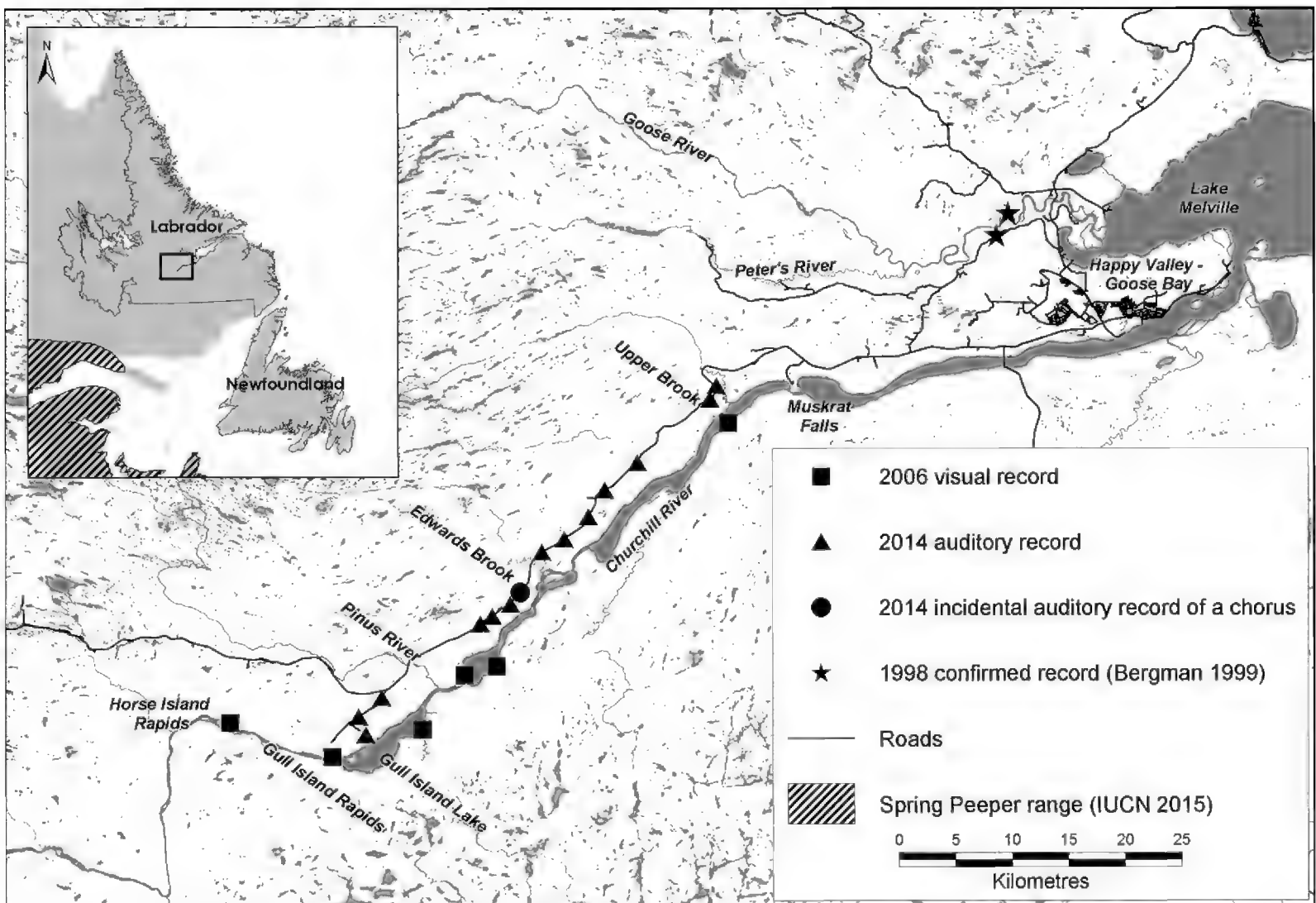


FIGURE 1. Spring Peeper (*Pseudacris crucifer*) records in Labrador, Canada.

To gain a more complete understanding of the extent of Spring Peeper distribution within our study area, we conducted systematic auditory surveys in 2014. Twenty-three locations along the lower Churchill River Valley were surveyed over three evenings, 16–18 June, coinciding with the expected breeding period for Spring Peeper (based on calling activity) in the region. Auditory survey locations were spaced a minimum of 0.8 km apart (based on standard operating procedures: nocturnal amphibian survey [unpubl.]; Stantec, Corner Brook, Newfoundland and Labrador; March 2014) along road-accessible areas between Gull Island Lake (52.9845°N, 61.3543°W) and Muskrat Falls.

Surveys started ~0.5 h after sunset (between 2110 and 2130) and were conducted only when winds were <20 km/h, there was little or no precipitation, and air temperatures were >10°C. At each stop, a two-person team listened for calling Spring Peepers for 5 minutes. If the number of Spring Peepers calling could not be distinguished (because of call overlap), we estimated a range for the total number of Spring Peepers in the area (e.g., 6–10 individuals).

Results

During the 2006 ground surveys, we found nine Spring Peepers at six locations (Table 1). On 24 July, three recently transformed froglets (Figure 2a) and

one adult (Figure 2b) were found in a wetland complex made up of bog, swamp, and shallow water, located at 53.2247°N, 60.8640°W (Figure 2c). Between 23 and 27 July, five adults were found at five other locations between Horse Island Rapids and Pinus River (53.0363°N, 61.1796°W; Table 1). We did not capture and preserve any of the frogs encountered but took representative images (Figures 2a and 2b) that have been deposited in the natural history collections of The Rooms Provincial Museum (NFM HE-121).

During the 2014 auditory surveys, we documented Spring Peepers calling at an additional 13 locations (Table 1). We documented 6–10 individuals at three locations, 2–5 individuals at another three locations, two individuals at two separate locations, and a single individual at the remaining five locations. We did not make any audio recordings of the calls. All Spring Peeper observations in 2014 were from locations different from those identified in 2006. We did not hear any choruses during the surveys; however, K.R.R. previously heard a Spring Peeper chorus within the study area (53.0942°N, 61.1457°W) while conducting avifauna surveys in late May of the same year. This location, a shallow water wetland along the Trans Labrador Highway, was visited again during auditory sampling on 14 June, but no Spring Peepers were calling at that time.

TABLE 1. Visual and auditory records of Spring Peepers (*Pseudacris crucifer*) in the lower Churchill River Valley, Labrador, Canada, in 2006 and 2014. For the auditory records, the general location and coordinates indicate the position of the biologist during the survey.

General location and habitat	No. peepers	Year	Date	Survey type	Location
Alder (<i>Alnus</i> sp.) shrub habitat on the banks of a tributary inflow to the Churchill River (southside) near Gull Island Lake	1 adult	2006	July 23	Visual	52.9880°N 61.2794°W
Open fen/bog along the northside of the Churchill River near Horse Island Rapids	1 adult	2006	July 23	Visual	52.9965°N 61.5323°W
Wetland along the southside of the Churchill River near Pinus River	1 adult	2006	July 23	Visual	53.0363°N 61.1796°W
Bog/swamp/shallow water wetland complex along the southside of the Churchill River near Lower Brook.	1 adult	2006	July 24	Visual	53.2247°N 60.8640°W
	3 juveniles				
Open bog along the northside of the Churchill River near Gull Island rapids	1 adult	2006	July 25	Visual	52.9675°N 61.3989°W
Mixed deciduous forest along the northside of the Churchill River near Pinus River	1 adult	2006	July 29	Visual	53.0302°N 61.2225°W
Gull Island road	6–10	2014	June 16	Auditory	52.9988°N 61.3633°W
Gull Island road	2–5	2014	June 16	Auditory	52.9988°N 61.3633°W
Gull Island road	1	2014	June 16	Auditory	53.0137°N 61.3322°W
TLH* between Pinus River and Edwards Brook	1	2014	June 16	Auditory	53.0703°N 61.1996°W
TLH between Pinus River and Edwards Brook	2–5	2014	June 16	Auditory	53.0762°N 61.1836°W
TLH near Edwards Brook	1	2014	June 16	Auditory	53.1261°N 61.1158°W
TLH between Pinus River and Edwards Brook	2	2014	June 17	Auditory	53.0852°N 61.1594°W
TLH between Edwards Brook and Lower Brook	2	2014	June 17	Auditory	53.1360°N 61.0857°W
Along the TLH	6–10	2014	June 17	Auditory	53.1529°N 61.0531°W
Along the TLH	1	2014	June 17	Auditory	53.1739°N 61.0308°W
TLH between Edwards Brook and Lower Brook	6–10	2014	June 17	Auditory	53.1952°N 60.9862°W
TLH between Edwards Brook and Lower Brook	1	2014	June 18	Auditory	53.2439°N 60.8875°W
TLH between Edwards Brook and Lower Brook	2–5	2014	June 18	Auditory	53.2543°N 60.8785°W

*TLH = Trans Labrador Highway.

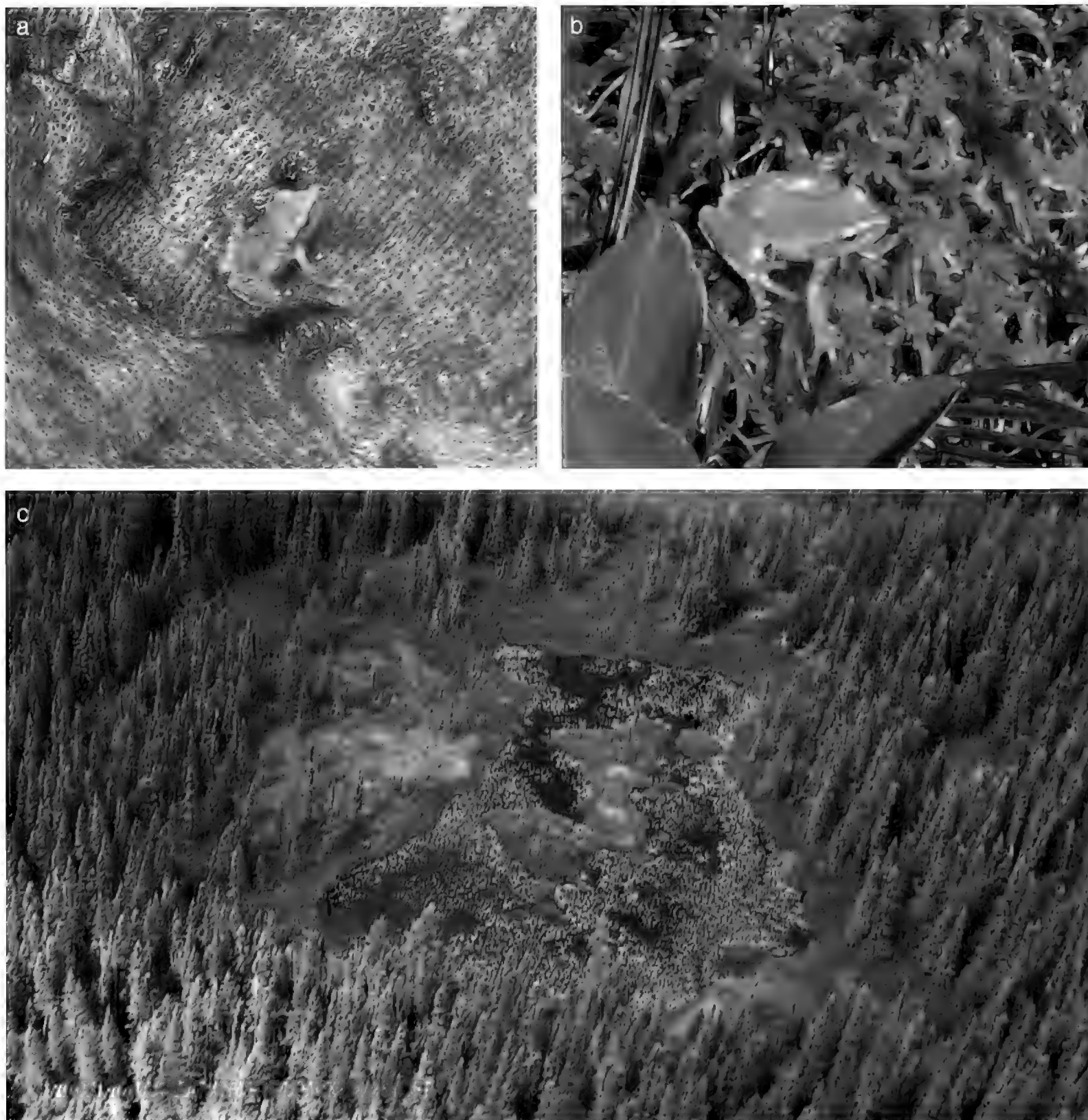


FIGURE 2. Spring Peepers (*Pseudacris crucifer*) captured in a small wetland complex adjacent to the main stem of the lower Churchill River, Labrador, on 24 July 2006 (53.2247°N, 60.8640°W). a. Recently transformed Spring Peeper captured in a dip net. b. Adult Spring Peeper found in a peat moss (*Sphagnum* sp.) dominant carpet punctuated by patches of low shrubs, graminoids, and forbs. c. Aerial view of the location of Spring Peeper captures. Photos: M.D. MacDonald.

Discussion

To date, all tangible records of Spring Peepers in Labrador have been from within the High Boreal Forest (Lake Melville) Ecoregion (Meades 1990). This ecoregion is considered unique in Labrador in that summers are warmer and shorter and winters less severe than in the adjacent ecoregions (Meades 1990; Way *et al.* 2016). The ecoregion itself has been described as a “thermal oasis” because it supports several species, including Leopard Frog (*Lithobates pipiens*), that are typically only found further south (Maunder 2016). The occurrence of more “southern” species in the ecoregion

has been attributed to a historical northward shift in warm temperatures and, consequently, warmer-area species, followed by a southward shift and subsequent cooling that left some of those species trapped in the area (Maunder 2016; see also Vilks and Mudie 1983; Way *et al.* 2016).

Relative to our study area in the lower Churchill River, the nearest records of Spring Peepers are from >400 km away, near Sept-Îles, Quebec (Bleakney 1954; Bider and Matte 1996) and, possibly, western Labrador near Menihek Lake Camp (Bleakney 1954). As such, Spring Peeper populations near Happy Valley-Goose

Bay and along the lower Churchill River Valley appear to be functionally isolated from neighbouring populations to the south and west and are considered “disjunct”. However, as we did not survey any areas outside of the lower Churchill River Valley and given the limited amphibian-related research in Labrador in general, it remains possible that Spring Peepers, like Wood Frogs (*Rana sylvatica*; Chubbs and Phillips 1998), occur in isolated populations elsewhere in Labrador. Whether the populations of Spring Peepers documented here and by Bergman (1999) are disjunct from populations in neighbouring Quebec requires further study.

Before our study, the only confirmed record of Spring Peepers in Labrador was Bergman’s (1999) account of this species near Happy Valley-Goose Bay. Here, we documented the presence of Spring Peeper over a larger geographic area in central Labrador, including 19 areas south and west of Bergman’s observations. Bergman indicated that the closest confirmed record of Spring Peeper was 500 km to the southwest of her observation, near Sept-Îles, Quebec. Our study has narrowed this gap by approximately 80 km and has provided additional information on this species at the extreme north-eastern edge of its range.

Acknowledgements

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Long-toed Salamander (*Ambystoma macrodactylum*) hibernacula in Waterton Lakes National Park revealed using Passive Integrated Transponder telemetry

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Abstract

Long-toed Salamanders (*Ambystoma macrodactylum*) spend most of their lives on land; however, their fossorial nature makes studying their use of habitat difficult. Using Passive Integrated Transponder (PIT) telemetry over two years, we found and characterized nine overwintering sites of Long-toed Salamanders in the vicinity of Linnet Lake and Stable Pond in Waterton Lakes National Park, excavating five of them. These sites were typically associated with stumps and decaying root systems that gave the salamanders access to deep subterranean hibernacula. Overwintering sites were located up to 168 m from the shores of breeding ponds. Given the importance of such terrestrial sites to these populations of Long-toed Salamanders, it is vital that conservation efforts include the preservation of these features and ensure that a sufficient area surrounding breeding ponds remains undisturbed.

Key words: Long-toed Salamander; *Ambystoma macrodactylum*; amphibian; terrestrial habitat; conservation; overwintering refugia; Waterton Lakes National Park; Alberta

Introduction

Long-toed Salamander (*Ambystoma macrodactylum*) is a widespread, relatively common species of “mole salamander” (Ambystomatidae) of western North America, whose Canadian range includes portions of British Columbia and Alberta (Petranka 1998; Lee-Yaw and Irwin 2012). In Alberta, it is patchily distributed, mainly along the east slopes of the Rocky Mountains, defining the northeastern edge of the species’ global range. Isolated Alberta populations occur near Fairview in the north and Stavely in the south (Russell and Bauer 2000).

Provincially, Long-toed Salamander is listed as a species of special concern (Alberta Environment and Parks 2014). Although Alberta’s populations of the Long-toed Salamander currently appear stable, a number of threats have been identified. These include energy sector and forestry activity, urbanization, fish stocking, and the widespread construction of roads near breeding ponds (Graham and Powell 1999).

Long-toed Salamanders in Alberta breed mainly in shallow, productive, fish-free ponds and lakes in a variety of landscape types (Graham and Powell 1999; Pearson 2004). Adults enter breeding ponds at ice-off and leave by early summer, whereas larvae metamorphose and leave ponds in late summer and early fall (Graham and Powell 1999). Use of the terrestrial environment by juveniles and adults has been more diffi-

cult to document because of the subterranean habits of the species. During the active season, Long-toed Salamanders, like other mole salamanders, are typically found in the leaf litter and emerge on moist nights to forage for invertebrate prey. In Alberta, they occupy home ranges of 115–280 m² and can travel up to 900 m from breeding ponds to reach these sites (Sheppard 1977; Graham 1997).

Little is known about the species’ overwintering locations. In the single study exploring this aspect of habitat use in Alberta, Sheppard (1977) employed radioactive marking to locate three Long-toed Salamander hibernacula in the Bow Valley. Information on overwintering behaviour can be critical for the conservation of northern amphibian populations, where the existence of appropriate hibernation sites, near breeding ponds and foraging habitat, may dictate the size, distribution, and persistence of populations (Browne and Paszkowski 2010).

Fine-scale patterns of terrestrial habitat use are often difficult to document for amphibians at any time of year, because of their small body size and cryptic nature. Technical limitations come into play when applying tracking devices to small-bodied vertebrates, either internally or externally, and transmitters can affect behaviour and survivorship (Weatherhead and Blouin-Demers 2004; Barron *et al.* 2010). However, radio-frequency identification (RFID) and Passive Integrated

Transponder (PIT) technologies provide a convenient method for investigating habitat use and movement patterns of small species, including amphibians (Cucherousset *et al.* 2008; Hamed *et al.* 2008; Connette and Semlitsch 2012; Ryan *et al.* 2014). PIT tags and “PIT telemetry” can liberate investigators from the size constraints and battery-life limitations of conventional radio telemetry.

We used this technology to study a population of Long-toed Salamanders in Waterton Lakes National Park in southwestern Alberta. The Long-toed Salamanders breeding in Linnet Lake and nearby Stable Pond have been the subject of research since the 1990s, in part because of mortality of migrating salamanders on the adjacent Entrance Road (Fukumoto and Herrero 1998). In 2008, four tunnels under Entrance Road were installed to reduce roadkill at Linnet Lake (Pagnucco *et al.* 2012). We captured Long-toed Salamanders at Linnet Lake (2013, 2014) and Stable Pond (2014) and PIT tagged them. At Linnet Lake our fundamental objective was to assess tunnel use with stationary RFID antennae as animals moved to and from this breeding site (Atkinson-Adams 2015). In addition, we used PIT telemetry to investigate the use of terrestrial habitat surrounding breeding sites during the summer and fall of 2013 (Linnet Lake) and 2014 (Stable Pond). One goal of these surveys was to locate Long-toed Salamander hibernation sites and characterize their

above- and below-ground features. We postulated that one reason that Long-toed Salamanders crossed Entrance Road was to move between aquatic breeding sites and specific terrestrial macro- or micro-habitats required for overwintering.

Study Area

Research centred on two breeding sites in Waterton Lakes National Park, Alberta: Linnet Lake (in 2013 and 2014) and Stable Pond (in 2014; Figure 1). Linnet Lake (49.07°N, 113.9°W) is a small (3.9 ha), shallow (5 m maximum depth) lake at an elevation of ~1260 m in a bowl-like catchment basin. The vegetation around the lake is dominated by stands of Douglas Fir (*Pseudotsuga menziesii* (Mirbel) Franco) and poplar (*Populus* spp.), with an understorey of small trees and shrubs, such as Chokecherry (*Prunus virginiana* L.), Saskatoon (*Amelanchier alnifolia* (Nuttall) Nuttall ex M. Roemer), and Snowberry (*Symphoricarpos albus* (L.) S.F. Blake). The lake is surrounded by a moderately steep hillside (slope up to 15%) except on the north end, which is a flat, low-lying area adjacent to Middle Waterton Lake. The park's Entrance Road runs along the west side of the lake at a straight-line distance of 13–110 m. The stretch of this road bordering the lake is punctuated by four salamander tunnels spaced ~80–110 m apart (described in detail by Pagnucco *et al.* 2012). Linnet Lake is inhabited by three fish species: White Sucker

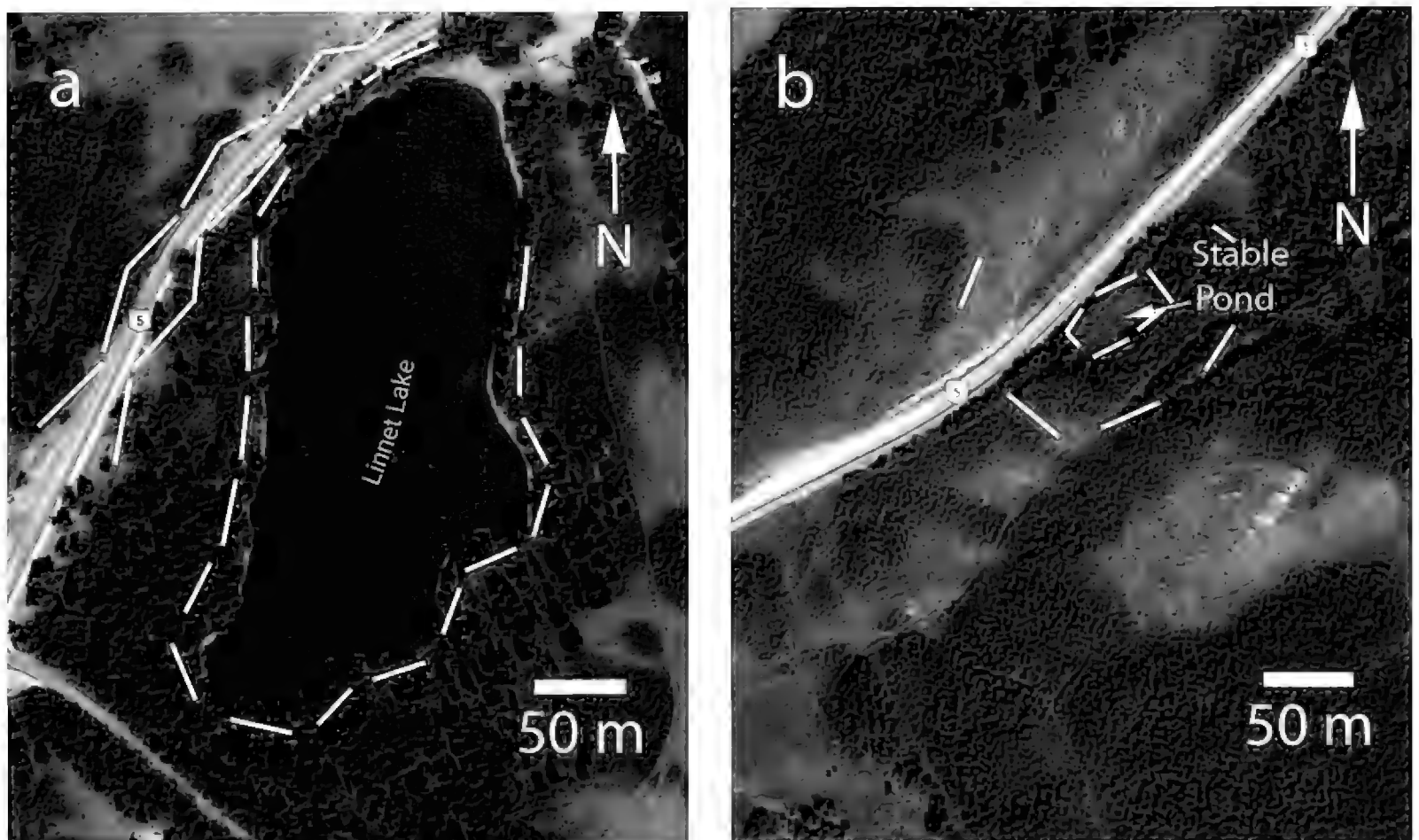


FIGURE 1. Images of the two study sites in Waterton Lakes National Park, Alberta. a. Linnet Lake. b. Stable Pond, which is 1.2 km northeast of Linnet Lake. Entrance Road (Highway 5) runs west of each water body. The approximate location of our drift fences and, in the case of Linnet Lake, permanent fencing along Entrance Road are indicated by white lines. Source: Linnet Lake, 49.07°N, 113.9°W; Stable Pond, 49.07°N, 113.88°W. Data provider: Imagery, DigitalGlobe (2017); Map data, Google Canada (2017). Date Accessed: 1 May 2018.

(*Catostomus commersonii*), Longnose Sucker (*Catostomus catostomus*), and Lake Chub (*Couesius plumbeus*). Western Toads (*Anaxyrus boreas*) and Western Tiger Salamanders (*Ambystoma mavortium*) are also found on site.

Stable Pond (49.07°N, 113.88°W) is a small (0.15 ha), fishless pond 1.2 km to the northeast of Linnet Lake, at an elevation of 1275 m. With a maximum depth of 1.6 m, it typically dries up by midsummer (22 July in 2013, 7 August in 2014) to become a grass-dominated meadow. Stable Pond is surrounded by poplar forest and flat terrain that breaks into open grass and low shrubs to the south and poplar forest with isolated stands of Douglas Fir to the east. To the west, the pond is immediately bordered by Entrance Road. Western Toads and Boreal Chorus Frogs (*Pseudacris maculata*) also breed in Stable Pond.

Methods

Salamander capture

To capture salamanders at Linnet Lake, a series of 16 (2013) or eight (2014) 30-m drift fences (silt fencing, 1 m high) were installed 10–25 m from the lake to create temporary barriers to salamander movement; no pitfall traps were employed here (Atkinson-Adams 2015). In addition, four permanent fences (corrugated plastic, 45 cm high) designed to keep salamanders off the road and to funnel them into the under-road tunnels were present on both sides of Entrance Road, each varying in length from 40 m to 123 m. Fences were walked nightly beginning on 25 April in 2013 and on 17 April in 2014; all salamanders were captured and held for identification or marking (see below). Nightly searches continued until five consecutive nights passed with no salamander encounters, which occurred in late June in both years. Searches were re-initiated on the next rainy night and continued nightly until no salamanders were encountered (8 July in 2013 and 2 July in 2014). Salamanders were also opportunistically caught around Linnet Lake and on Entrance Road.

In 2014, drift fences (silt fencing, 1 m high) were installed to capture salamanders at Stable Pond: a series of five 30-m fences, 3 m from the high waterline and five 30-m fences, 50 m from the high waterline (Atkinson-Adams 2015). Fifty pitfall traps, made from #10 food service cans (15.9 cm in diameter, 17.8 cm deep), were buried either along both sides of fences (April–June) or only along the pond side of fences (July–August) to capture young-of-the year (YOY). Ten minnow-traps (42 cm × 19 cm, 6.4-mm mesh, 2.5-cm openings) were placed in the pond, evenly spaced around the perimeter, to trap breeding adults. Traps were checked daily, usually within 1 h of sunrise. Handling of captured salamanders was the same as described above for Linnet Lake.

Salamander marking

Captured salamanders from a single fence or trap were placed individually on moist paper towelling in

a site-labelled plastic container and transported to an indoor laboratory for marking and identification. Recaptured, PIT-tagged salamanders were individually identified with a hand-held half-duplex (HDX) proximity reader (Datamars, Lamone, Switzerland). Unmarked juvenile and adult salamanders were anaesthetized by immersion in 1 g/L trimethane sulfonate solution until unresponsive to prodding (typically 6–10 minutes). Salamanders with swollen vents (could be sexed) were considered mature adults, and smaller salamanders without swollen vents (could not be sexed) were considered juveniles. Juvenile salamanders captured at Stable Pond in July and, later, those bearing gill remnants behind the jaw were considered YOY. No YOY were seen at Linnet Lake.

PIT tagging involved the insertion of a 12 mm × 2.12 mm sterile HDX PIT tag (Texas Instruments, Dallas Texas, USA) weighing 0.1 g (10% of body weight maximum, typically <2%) into the body cavity via a 3-mm incision made using a fresh #11 scalpel blade just anterior to the right hind leg and slightly toward the midline. The incision was closed with Vetbond Tissue Adhesive (3M, St. Paul, Minnesota, USA), which was applied to the dried incision while holding the opposing edges of the incision together with forceps. Consistent with other studies on urodeles, PIT-tag implantation had no apparent short-term effects on salamander behaviour or survival (e.g., Ott and Scott 1999). PIT-tagged animals were also marked either by clipping the second phalangeal joint on toe three of the right hind leg or through injection of red or orange visual implant elastomer (Northwest Marine Technologies, Shaw Island, Washington, USA) subdermally at the ventral base of the tail just posterior to the vent. After wound closure, salamanders were placed in a container of non-chlorinated water shallow enough to allow their heads to remain above water until they recovered from anaesthesia (typically 10–15 minutes). Once recovered (moving, responsive to prodding), individuals were placed in their original containers and released within 3 h near the point of capture.

Using PIT telemetry to locate overwintering salamanders

We began using PIT telemetry to search the terrestrial environment for tagged salamanders after peak migration of adults from breeding sites (4 June 2013 at Linnet Lake and 9 June 2014 at Stable Pond). Scanning was performed to document movement patterns and habitat use by adults and juveniles in summer (not reported here, see Atkinson-Adams 2015) and to identify locations to survey for hibernating salamander in fall. In both years, scanning was initiated near the shoreline, working outward to areas ~200 m from shore in a series of rectangular transects during the summer season, ending on 29 August in both years. We scanned 98 850 m² at Linnet Lake and 51 450 m² at Stable Pond following methods described in Kuhnz (2000).

Walking in straight-line transects, we brought a hand-made RFID scanner as close as possible to the ground and swept side-to-side (see Atkinson-Adams *et al.* 2016). Transects were 30 m long with overlap between adjacent transects to minimize unscanned terrain. The scanner was a wand-like portable RFID antenna used in conjunction with a tuning capacitor and HDX backpack reader (Oregon RFID, Portland, Oregon, USA) set to scan five times per second. The portable RFID antenna consisted of a 61-cm diameter antenna loop encased in sturdy plastic tubing attached to a length of polyvinyl chloride tubing (length ~2 m, diameter 3.2 cm). Systematic testing indicated a maximum vertical detection depth of ~72 cm in soil or rocky substrates with the scanner placed directly on the ground (Atkinson-Adams *et al.* 2016), which is comparable to the depths at which Sheppard (1977) found overwintering Long-toed Salamanders using radioactive tracers.

We scanned for overwintering Long-toed Salamanders 3–15 October 2013 at Linnet Lake and 15–23 November 2014 at Stable Pond. Based on values reported by Sheppard (1977), we assumed that adults had summer home ranges averaging 150 m², and that overwintering sites would be located within or near these home ranges. Thus, we returned to the location of the most recently detected individuals from summer scanning efforts (e.g., 28 August 2013 and 26 August 2014) and scanned a 30 m × 30 m (900 m²) plot orientated north–south and centred on the August location using the transect-scanning methods described above. In addition to scanning at known late-summer locations, we sampled a previously unscanned area across (west of) Entrance Road at Linnet Lake in 2013 and the dried bottom of Stable Pond in 2014.

Characterization of overwintering sites

When a salamander was detected during searches for overwintering sites, its location was marked and then returned to for investigation after the 30 m × 30 m plot was scanned completely. If multiple salamanders were detected in the same plot, sites were examined in the order in which they were found.

To characterize overwintering sites, aboveground features were recorded: dominant vegetation, light level, percentage cover, and number and type of aboveground objects. Then, an attempt was made to excavate the salamander to describe the underground hibernaculum and to see if other individuals were present. Light levels were measured as per cent transmittance (foot-candles) using a light meter (Model 217, General Electric, Boston Massachusetts, USA). Estimated per cent cover within a 1-m-diameter circular plot, centred on the site, were recorded: leaf litter, grass/forb, woody vegetation, small (<10 cm diameter) and large (≥10 cm diameter) woody debris, rock, moss, and bare ground. The number and type of aboveground objects—small (1.5–10 cm diameter) and large (≥10 cm diameter) trees, wood (bark, logs, or stumps), rocks ≥10 cm wide—and the presence of mammal burrows were determined

within a 2-m radius of the relocation site. After it was characterized, we carefully excavated the site with a spade until either the salamander was located with a hand-held HDX proximity reader (maximum read range ~12 cm) or it was determined that alterations caused by further digging would be too extensive to repair. Excavations were then returned as nearly as possible to their original state, including returning above- and below-ground material and re-establishing tunnels and air spaces to allow the replaced salamanders to emerge in the spring.

Results

PIT telemetry yielded reasonable rates of relocation for tagged Long-toed Salamanders using our hand-made RFID scanner (Atkinson-Adams *et al.* 2016) to survey terrestrial habitat. In summer, 32 of 404 tagged Linnet Lake salamanders (2013) and 82 of 629 tagged Stable Pond salamanders (2014) were detected in 81 and 83 days of scanning, respectively. The area surrounding both breeding sites was heavily vegetated and uneven, with scattered large rocks and woody debris, which limited the number of detections (Atkinson-Adams *et al.* 2016). We found little evidence that PIT tags were readily lost or were the cause of substantial mortality. Summer scanning uncovered five “naked” PIT-tags on or near the soil surface at Linnet Lake and 22 at Stable Pond, representing 2% and 9% of implanted tags, respectively. Tags may have been shed by living animals (Ott and Scott 1999) or may represent disintegrated carcasses of dead animals. At Stable Pond, we located intact carcasses of two salamanders that still contained PIT tags. Our surveys in October and November succeeded in uncovering hibernating sites. We located seven salamanders in fall 2013 (all with PIT tags) and nine salamanders in fall 2014 (seven with PIT tags, plus two additional individuals without tags co-occurring with tagged salamanders).

In October 2013, during 13 days of scanning at Linnet Lake, we sampled 14, 30 m × 30 m plots based on old locations and 12 500 m² of new area on the far side of Entrance Road. Seven salamanders were detected: one was 87 m west of Entrance Road, the others were east of the road (Figure 1). Three of the seven salamanders were located on the soil surface, <5 cm deep in the leaf litter, 74 m, 127 m, and 143 m from the shoreline of Linnet Lake. When revisited on 15 October, after a spell of warm weather (day-time high of 12°C), these three individuals were gone; thus, these locations were not considered to be hibernation sites and are not described in Table 1. A different individual was detected at one of these locations on 12 April 2014 (under 10–20 cm snow) and 19 April (no snow), but was absent in May, only to be detected again on 16 November 2014. Three of the salamanders had been previously relocated following PIT tagging and were 15 m, 19 m, and 134 m from the earlier locations.

TABLE 1. Characteristics of overwintering sites for Long-toed Salamanders (*Ambystoma macrodactylum*) located using Passive Integrated Transponder (PIT) telemetry in Waterton Lakes National Park, Alberta. Habitat data were collected within a 1-m diameter circular plot centred on the relocation site.

Linnet Lake, 2013										Stable Pond, 2014				
PIT number	135912	501602/90267	135798	501702/517467	501608	522687	517363	501711	511365					
Sex of salamander*	F	F/F	M	M/F	M/(M)	YOY	M/(J)	M	F					
SVL, mm	71.2	71.4/71.3	66.0	57.2/66.5	61.5	35.5	58.2	61.2	71.7					
Weight, g	7.7	5.6/6.7	5.8	3.3/4.4	4.6	ND	3.7	4.5	7.2					
Date	8 Oct.	12 Oct.	13 Oct.	20 Nov.	20 Nov.	21 Nov.	21 Nov.	21 Nov.	23 Nov.					
Refuge type	Stump	Stump	Stump/burrow	Stump	Root	Root	Root	Root	Root					
Depth, cm	ND	ND	ND	ND	28	28	27	30	38					
Distance from shore, m	168	85	25	3	118	52	47	49	92					
Dominant vegetation†	Shrub	Grass	Conif./decid.	Decid.	Decid.	Decid.	Decid.	Decid.	Decid.					
Light, %	58	50	22	38	38	47	31	46	47					
Slope, %	11	4	5	6	3	6	5	6	3					
Aspect, °	116	5	56	225	243	216	208	216	225					
Leaf cover, %	20–29	70–79	30–39	1–9	1–9	1–9	1–9	ND	1–9					
Dried grass cover, %	1–9	60–69	1–9	1–9	1–9	1–9	1–9	ND	1–9					
Woody plant cover, %	1–9	10–19	1–9	10–19	10–19	10–19	1–9	ND	1–9					
Grass/forbs cover, %	1–9	1–9	1–9	1–9	1–9	1–9	1–9	ND	1–9					
LWD cover, %	10–19	0	1–9	10–19	0	0	0	ND	20–29					
SWD cover, %	1–9	1–9	10–19	0	0	0	1–9	ND	1–9					
Rock cover, %	1–9	0	0	0	0	0	0	ND	0					
Bare ground, %	20–29	0	10–19	0	0	0	0	ND	0					
Moss cover, %	0	1–9	10–19	0	0	0	0	ND	0					
Snow cover, %	0	0	0	80–89	80–89	70–80	80–90	ND	60–70					
No. trees ≥10 cm diameter	0	0	3	1	5	3	2	2	1					
No. trees <10 cm diameter	21	6	6	26	22	21	5	22	0					
No. woody features	4	4	5	2	1	2	0	0	2					
No. rocks	2	0	0	0	ND	0	0	0	ND					
No. burrows	1	1	8	0	ND	0	1	ND	ND					

Note: LWD = large woody debris, ND = not determined, SVL = snout-to-vent length, SWD = small woody debris.
*F = female adult, M = male adult, YOY = young-of-year, J = juvenile, () = untagged (found with PIT-tagged individuals 501608 and 517363). Sex and size information are available only for PIT-tagged animals and were collected at the time of tagging.
†Conif./decid. = coniferous and deciduous tree species.

For the three apparent hibernation sites at Linnet Lake, it was not possible to excavate salamanders to determine actual depth, precise refuge type, or presence of other occupants. All three locations, one of which contained two PIT tagged individuals, were within 2 m of old rotten stumps of coniferous or deciduous trees and were at estimated depths >25 cm based on adjacent excavations and combined readings from our custom-made RFID scanner and a hand-held HDX proximity reader (maximum read range ~12 cm). Three salamanders appeared to be in the matrix of decomposed roots associated with the stump itself and one appeared to be within a network of small mammal tunnels in the slope immediately below the stump, which, based on the presence of cone scales, were likely used by Red Squirrels (*Tamiasciurus hudsonicus*). Sites were 25–168 m from the shoreline of Linnet Lake. We found no pattern in vegetation cover or larger-scale characteristics of overwintering sites (Table 1). The dominant vegetation varied among sites and was deciduous trees, a mix of coniferous and deciduous trees, shrubs, or grass. Detailed characteristics of the sites are presented in Table 1.

In November 2014, during nine days of scanning at Stable Pond, we sampled eight, 30 m × 30 m plots, including the dried pond bed. The weather was cold (reaching a low of −26°C), with 12 cm of snow on the ground. We detected nine salamanders in six hibernation sites, 3–118 m from the edge of Stable Pond's high-water limit (Table 1). Detected sites were all in areas dominated by deciduous trees. As had been seen at Linnet Lake, one site was clearly associated with a stump, and two PIT-tagged individuals were detected there. The stump was not excavated, but salamanders appeared to be within the rotten wood matrix of the trunk and its roots at a depth of ~36 cm. The other five overwintering sites at Stable Pond were not obviously associated with specific aboveground objects, but logs and/or large deciduous trees were present within 2 m. These five sites were excavated, and two contained a second, untagged salamander. The seven salamanders were 28–38 cm below the ground surface within cavities left by decomposed roots 1.5–3 cm in diameter (likely *Populus* spp.). In all cases, the bark of the roots maintained their shapes even when no wood remained inside, thus creating tiny tunnels. One of the salamanders was one of 44 PIT-tagged YOY. Three of these salamanders had also been detected at Stable Pond during scanning in the summer at locations 10 m, 20 m, and 168 m from their hibernation sites. Additional characteristics of Stable Pond sites are presented in Table 1.

Discussion

Overwintering macro- and micro-habitats are critical to northern terrestrial salamanders, as they spend a good portion of the year in these locations (Petranka 1998), which are vulnerable to natural and anthropogenic disturbances year-round. Knowledge of how far away from breeding ponds anurans and salamanders hiber-

nate can help to establish conservation buffers to prevent unintended site degradation and destruction (Semlitsch and Bodie 2003). At our study sites in Waterton Lakes National Park, hibernacula of Long-toed Salamanders located using PIT telemetry were within 3 m and 168 m of breeding sites. Overwintering sites are likely much more distant for many individuals, especially those breeding in Linnet Lake. Using RFID antennas at openings for two of the four under-road tunnels, we detected 22% of 404 PIT-tagged salamanders in 2013 and 10% of 643 PIT-tagged salamanders in 2014 moving through these structures. These individuals would have travelled at least 200 m between their breeding lake and terrestrial habitat on the other side of Entrance Road.

What terrestrial macrohabitat features Long-toed Salamanders might have been seeking in crossing the road after breeding remains unclear. Vegetation cover surrounding hibernacula, for example, simply reflected the dominant plants growing around the breeding lake and pond. At a finer scale, Long-toed Salamanders in the vicinities of Linnet Lake and Stable Pond were found to overwinter in microhabitats created by the decomposing wood of tree stumps and their root systems. They also used tunnels at the interface of the decaying wood and the soil. The origin of these tunnels was unknown, but they may have been made by mammals or invertebrates. Monitoring of the under-road tunnels at Linnet Lake with cameras documented the presence of Deer Mice (*Peromyscus maniculatus*), shrews, voles, ground squirrels (*Spermophilus* spp.), chipmunks (*Tamias* spp.), and Red Squirrels at the site (Pagnucco 2010). The use by salamanders of burrows created by small mammals is well documented, including the use by Jefferson (*Ambystoma jeffersonianum*) and Spotted Salamanders (*Ambystoma maculatum*) of vertically oriented tunnels as overwintering sites (Madison 1997; Faccio 2003). Further north in Alberta's Aspen Parkland, Western Toads hibernate in below-ground tunnel systems linked to Red Squirrel cone middens (Browne and Paszkowski 2010) and Western Tiger Salamanders use Northern Pocket Gopher (*Thomomys talpoides*) burrows (Welsh 2016).

Inspection of three stumps that contained salamanders uncovered vertical tunnels within the soft, flakey wood that created spaces for salamanders to travel through and find shelter. Seven salamanders, located at five overwintering sites within poplar stands at Stable Pond, occupied similar passageways inside isolated complexes of hollow, rotten roots at depths >25 cm that were not connected to stumps or living trunks (Table 1). Thus, various forms of standing, downed, and buried woody debris appear to offer appropriate hibernating conditions for Long-toed Salamanders at Waterton Lakes National Park, whether surrounded by grass, shrubs, or trees. Snow cover is likely very important in insulating these sites, as we estimated that the depth of the frost line at Waterton Lakes, based purely on freezing index degree-days, is ~1400 cm (Urecon Ltd.

2018). However, the park is one of the wettest areas in Alberta with an average annual total snowfall of 575 cm at the town site (Parks Canada 2017), which is 1.3 km from Linnet Lake; thus, hibernating salamanders at shallower soil depths are likely protected from freezing. We located salamanders at a narrow range of depths, 27–38 cm. Our locations may not represent the true hibernation depths typical for these Long-toed Salamander populations, but instead reflect the limitations of PIT tag telemetry or the depths of temporary, early-season refugia from which animals eventually move deeper into the soil matrix.

Our findings share some aspects with Sheppard's (1977) observations for Long-toed Salamanders at a site ~250 km northwest of Waterton in the Bow River valley. Sheppard found Long-toed Salamanders overwintering in refugia associated with the roots of trees. However, at his study site, it appeared that salamanders moved below ground through the loose gravel substrate rather than using tunnels or decomposing root systems. Ambystomatid species differ in their digging abilities, some being active excavators, while others are passive excavators that use their wedge-shaped heads to widen existing spaces in the substrata (Semlitsch 1983). It is generally assumed that Long-toed Salamander is a passive excavator, but this has not been definitively shown. At Sheppard's sites, the trees and roots associated with overwintering sites were living spruce, and he makes no mention of mammal burrows or any other possible points of entry to below-ground areas. Also, his sites were in a relatively flat area consisting of glacial deposits, which had high soil moisture levels. With one exception, the hibernacula in our study were substantially uphill from the aquatic breeding pond.

Like Sheppard, we found Long-toed Salamanders overwintering communally, as eight of the 13 salamanders (61.5%) that we located occurred with a second individual. Sheppard found three juvenile salamanders overwintering with adults, and we also found one 1–2-year-old juvenile overwintering with an adult male, indicating that different age classes will share hibernacula. Juvenile Spotted Salamanders are attracted to burrows occupied by conspecifics, possibly an adaptation permitting naïve juveniles to find higher-quality refuges (Green *et al.* 2016). Long-toed Salamanders have been shown to express territorial behaviour, such as biting and avoidance (Ducey 1989); thus, the tolerance of conspecifics at hibernation sites that we observed may underscore the importance of these refuges and possibly their limited availability.

Despite the limitations of PIT-tag technology, such as low detection rates in rugged terrain or in dense vegetation and modest depth of detection, we were able to identify several salamander hibernacula in a relatively cost-effective manner (see also Ousterhout and Burkhart 2017). Our study has expanded knowledge of this poorly known, but important, aspect of the biology of Long-toed Salamander at the northeastern edge of

its distribution. Over its geographic range, the species is viewed as adaptable, occurring in habitats as varied as sage-brush and alpine elevations over 2700 m (Graham and Powell 1999; Werner *et al.* 2004). With respect to hibernation sites, we found the species to be flexible in terms of vegetation cover, but consistently occurring in microhabitats provided by decaying wood at and below the soil surface.

The persistence of populations of Long-toed Salamanders in Waterton Lakes National Park and elsewhere in Alberta requires the conservation of structurally complex terrestrial habitat around breeding ponds to provide both foraging and overwintering sites. Our results are consistent with the recent provincial recommendation for the creation of 250-m buffers, featuring forest patches with downed woody debris, around Long-toed Salamander breeding ponds (Alberta Environment and Parks 2016). We recommend the preservation of standing dead tree trunks and stumps in forested buffers, even after disturbances such as logging, insect outbreaks, and wildfire, as a management action that will provide winter microhabitat for the species.

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Checklist and status of the amphibians and reptiles of Essex County, Ontario: a 35 year update

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Abstract

Essex County, Ontario, supports a diverse assemblage of Canadian herpetofauna. It is home to the only Canadian populations of three species/subspecies and contains two of Canada's 11 Important Amphibian and Reptile Areas. A checklist and status assessment of the herpetofauna of Essex County was previously compiled in 1983. Changes to natural habitats and an increase in monitoring efforts (e.g., citizen science) over the past 35 years warrant an updated assessment of herpetofaunal status. The county was subdivided using a 10 × 10 km grid overlay, and recent observations (1997–2016) submitted to provincial databases were tabulated for each grid square. We compared current status of herpetofauna in Essex County to those of the 1983 study using a similar classification scheme of 'extirpated from Essex' (EE; no recent observations) and 'rare in Essex' (RE; distribution ≤5 squares). We found that 11 species declined in status. The majority of reptiles and amphibians (62%) that historically occurred in Essex County are now either EE (31%) or RE (31%) and almost half (45%) of the 29 extant species/subspecies are RE. A large proportion of salamanders and squamates are EE or RE (86% and 65%, respectively). Amount of natural area and sampling effort were important variables describing patterns of observed herpetofaunal species/subspecies richness, and observed richness was highest along the western and southern edges of the mainland (16–19 species). To prevent future extirpations, recovery efforts in Essex County should occur across multiple locations and target RE species.

Key words: Essex County; herpetofauna checklist; species status assessment; reptiles and amphibians; species richness; habitat loss; citizen science; Pelee Island; Ojibway Prairie Complex; endangered species

Introduction

Essex County is within Canada's Carolinian zone, an area with the greatest diversity of flora and fauna and one of the highest concentrations of globally rare species in all of Canada (ERCA 2002; Jalava *et al.* 2009). The county is very important to Canadian herpetofauna, in particular, as it contains the only Canadian populations of three species/subspecies (Blue Racer [*Coluber constrictor foxii*], Lake Erie Watersnake [*Nerodia sipedon insularum*], and Small-mouthed Salamander [*Ambystoma texanum*]), the only Canadian location of one extirpated species (Blanchard's Cricket Frog [*Acris blanchardi*]), and contains two of the 11 Important Amphibian and Reptile Areas in Canada (CHS 2017).

The first comprehensive checklist and status assessment of the herpetofauna of Essex County was compiled in the early 1980s as part of a detailed study of the Environmentally Significant Areas of the county (Oldham 1983, 1984a,b). This work provided a preliminary detailed account of each species/subspecies known to inhabit Essex County at that time, complete with historical observations. The work included results of herpetofaunal surveys at Point Pelee National Park (PPNP), Pelee Island, and Ojibway Prairie Complex (OPC), with supporting data derived from local naturalist's observations, museum collections, and the author's own extensive field work in the region (Oldham 1983).

Since that time, documentation of native herpetofauna has increased dramatically in Ontario and become more sophisticated. For example, in 1984 the Ontario Herpetofaunal Summary (OHS), a citizen science initiative, officially began its first year (Pulfer 2014). Annual reports detailing observation records were developed from 1984 to 1986 (Oldham and Sutherland 1986; Oldham 1988; Weller and Oldham 1988), mostly out of the Essex Region Conservation Authority (ERCA) office in Essex, Ontario. In 2009, Ontario Nature developed the Ontario Reptile and Amphibian Atlas (ORAA) by incorporating the OHS data, expanding herpetofaunal monitoring in the province, and increasing the number of observations for areas previously lacking data (Ontario Nature 2017). With continuing technological development, the submission, management, and display of observation records have advanced. For example, the ORAA has now logged over 3000 volunteer participants submitting over 350 000 observations (Ontario Nature 2015). Unfortunately, an increase in monitoring effort has been met with a decrease in availability and quality of reptile and amphibian habitat as urbanisation and agricultural activities intensify. For example, 78 ha of natural area were removed from within the Town of LaSalle for housing developments between 1986 and 1996 (Town of LaSalle 2016). At the turn of this century, 97% of wetlands and 95% of original forest cover

in Essex County had been lost, leaving the natural landscape in a highly degraded and fragmented state (ERCA 2002). Drastic changes in both the landscape as well as monitoring efforts over the last three decades warrant an updated assessment of the current herpetofauna of Essex County and its collective status.

Our goal was to provide an updated checklist and report on the status of the herpetofauna of Essex County since it was last assessed 35 years ago. Our questions were: 1) What is the current occupancy and distribution of herpetofauna in Essex County? 2) What is the trend in status of herpetofauna in Essex County over the last 35 years? and 3) In which areas of Essex County have the greatest number of herpetofaunal species/subspecies been reported?

Methods

We confined our study to the geographic boundary of the County of Essex (42.167°N, 82.783°W), which lies within the Carolinian Zone of southwestern Ontario. We subdivided the area using the same 10 × 10 km grid overlay used by the OHS and ORAA (Figure 1). Grid squares included those that contained landmass or islands (or a portion thereof) and at least one 'recent' reptile or amphibian observation ($n = 33$). Five potential grid squares were not included in the study as they either contained a portion of landmass/islands but no recent observations, or had recent observations but consisted entirely of open water. Current occupancy and distribution of herpetofauna in Essex County, in addition to species/subspecies richness per grid square, was determined primarily from observation records that were submitted to the ORAA within the previous 20 years (1997–2016; $n = 4226$) and available online (Ontario Nature 2017; records from other provincial or national databases were not included). Data were retrieved from the ORAA in winter 2017. Observation records ($n = 9$) for two species of turtle (Eastern Spiny Softshell [*Apalone spinifera spinifera*] and Spotted Turtle [*Clemmys guttata*]) were retrieved directly from the Natural Heritage Information Centre (NHIC 2017) because records for these species are not displayed by the ORAA. Additional resources were used to support regional status assessments as required (e.g., Committee on the Status of Endangered Wildlife in Canada [COSEWIC] and Committee on the Status of Endangered Wildlife in Ontario [COSSARO] status reports, academic journal articles, and books). All observations made between 1997 and 2016 were considered 'recent' and those made prior to 1997 were considered 'historical'.

The total number of 10 × 10 km squares with at least one recent observation was tallied for each species/subspecies. We classified species/subspecies with recent observations from ≤5 squares (≤15%) as rare in Essex County (RE), similarly to Oldham (1983). In almost all cases, we classified a species as extirpated from Essex County (EE) if no verified observations were submitted

in the past 20 years and if its current status was subjected to additional scrutiny from outside experts (e.g., species status reports, published accounts). A change in status from RE to EE does not necessarily imply a species became extirpated since the previous county-level status assessment. An extirpation event may have actually occurred prior to the 1980s; however, we argue that sufficient time has now passed and/or new studies have occurred to presume that a given species has become locally extirpated. Amphibians and reptiles that were not classified as RE or EE were recently reported from >5 squares (>15%) and therefore considered widespread.

The number of recent ORAA and NHIC observation records submitted from each 10 × 10 km grid square was tallied and displayed in a graduated map using natural breaks (jenks) in a geographic information system (GIS; ArcGIS 9.1, Esri, Redlands, California, USA; Figure 2). These data were used to summarize the number of herpetofauna species/subspecies reported within each 10 × 10 km grid square (i.e., observed richness). Observed richness was displayed in a graduated map using manual breaks in a GIS (Figure 3). Finally, the amount of natural area (i.e., land that has not been converted to agricultural, industrial, urban, or residential uses) present within each 10 × 10 km grid square was mapped by merging five distinct data layers (Table 1; we estimated 5.9% natural area remaining in Essex County, which is very similar to the 6.5% natural area estimated by ERCA [2002]). A Dissolve function was performed on the resultant natural area merged file to eliminate overlapping boundaries within each polygon. The Explode feature was used to separate the resultant natural area multipart feature into separate polygons. All polygons that occurred across multiple grid squares were then split along the intersecting grid line. In order to select polygons of natural areas in each individual grid square, the Select by Location feature was used. Summary statistics for the selected grid square were then obtained using the attribute table, with the sum representing hectares of natural area in the selected square. These data were then displayed in a graduated map using manual breaks in a GIS (Figure 4). We used linear regression in Microsoft Excel 2010 (version 14.0.7190.5000, Microsoft Corporation, Redmond, Washington, USA) to predict the number of herpetofauna species/subspecies reported per square (dependent variable) based on amount of natural area per square (independent variable). Due to a small sample size we did not account for the impact of spatial autocorrelation on species richness.

Results

Widespread herpetofauna of Essex County

Sixteen species (seven amphibians, nine reptiles) are widespread in Essex County based on recent observations within six or more grid squares (Table 2). Six species of anurans that were previously considered wide-

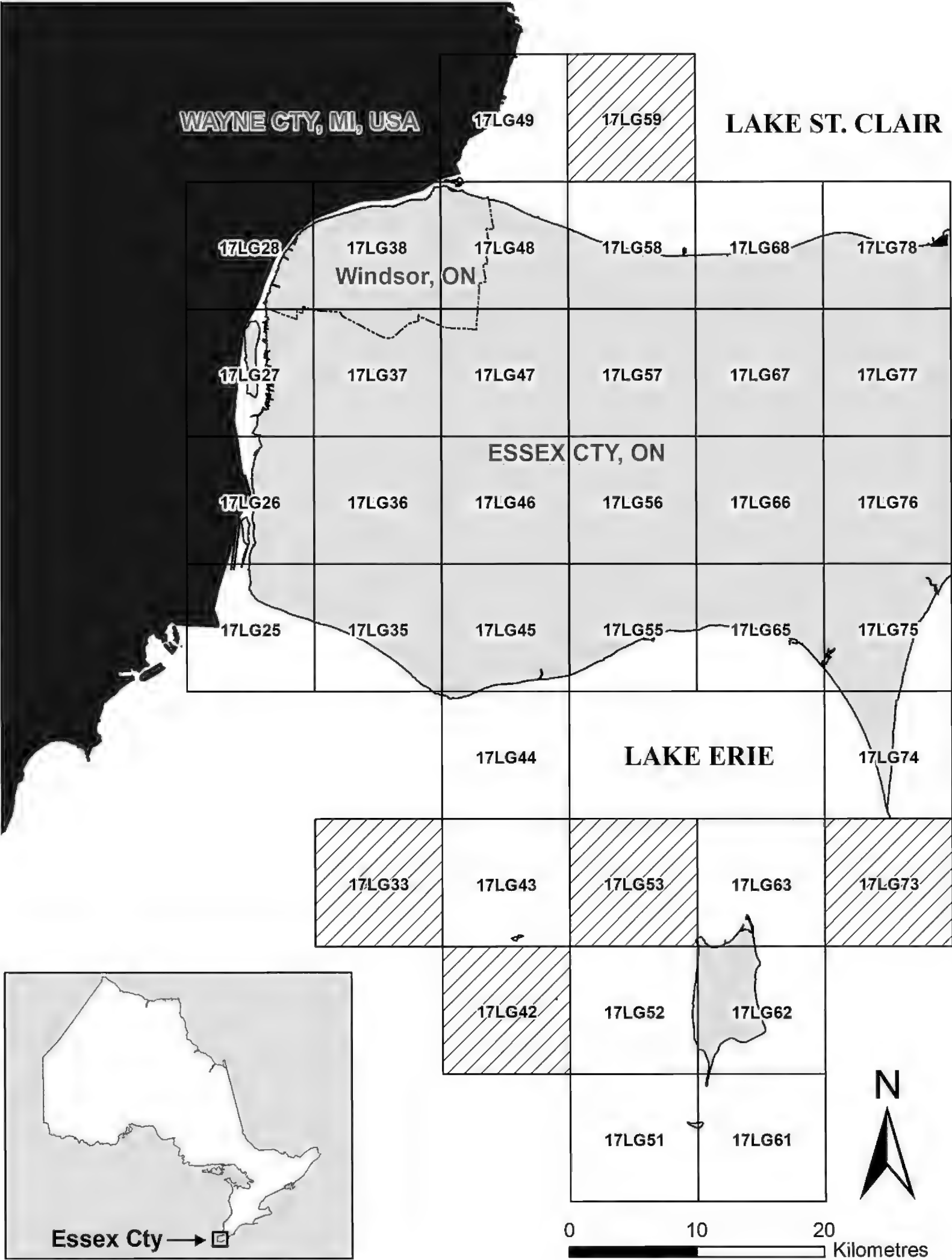


FIGURE 1. Map of Essex County, Ontario, showing 10 × 10 km grid overlay. Grid square labels correspond with those used by Ontario Nature (2018), and hatched grid squares were not included in the study.

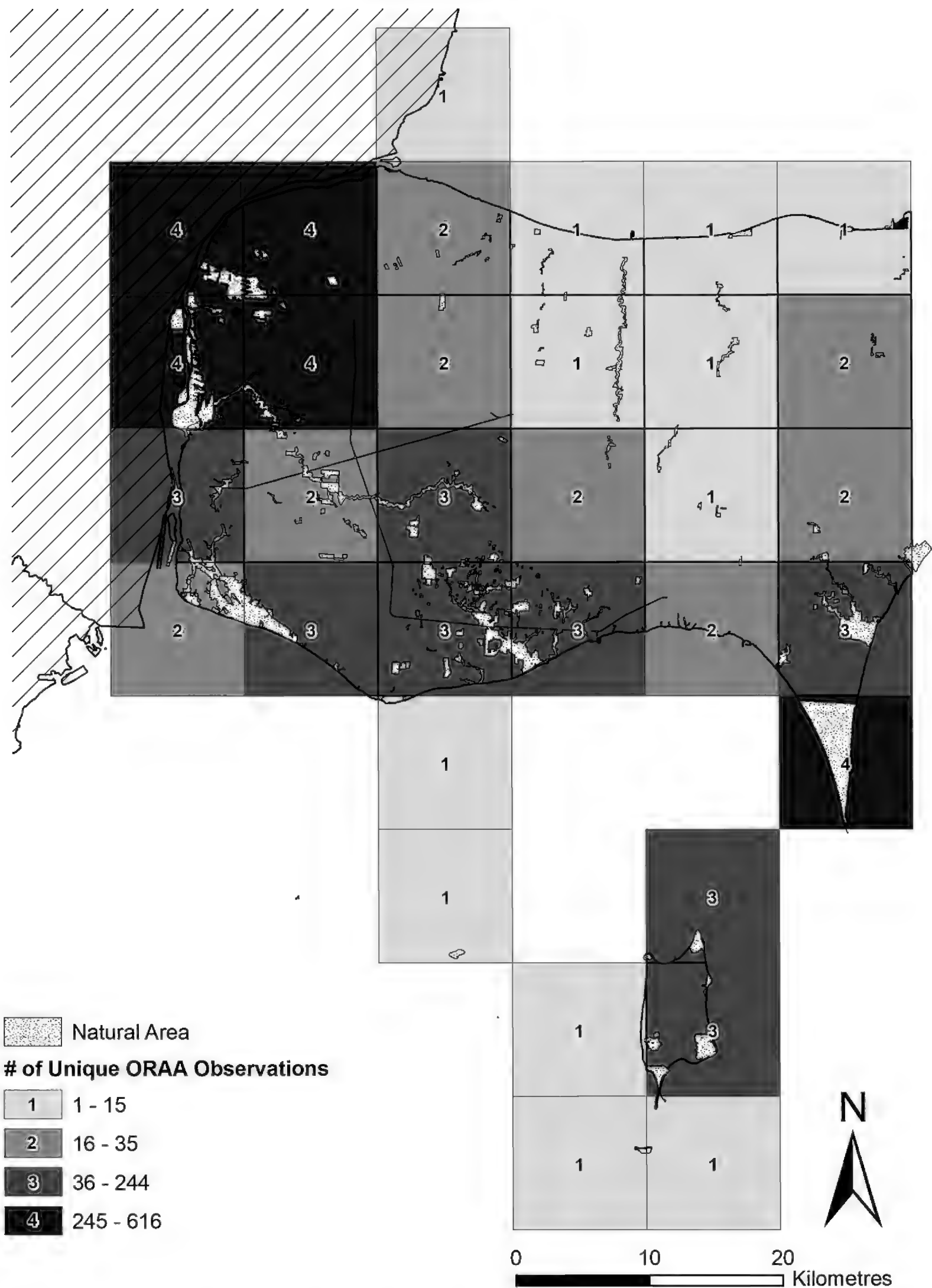


FIGURE 2. Number of recent reptile and amphibian observations submitted to the Ontario Reptile and Amphibian Atlas (ORAA) per grid square. See Table 1 for description of natural area.

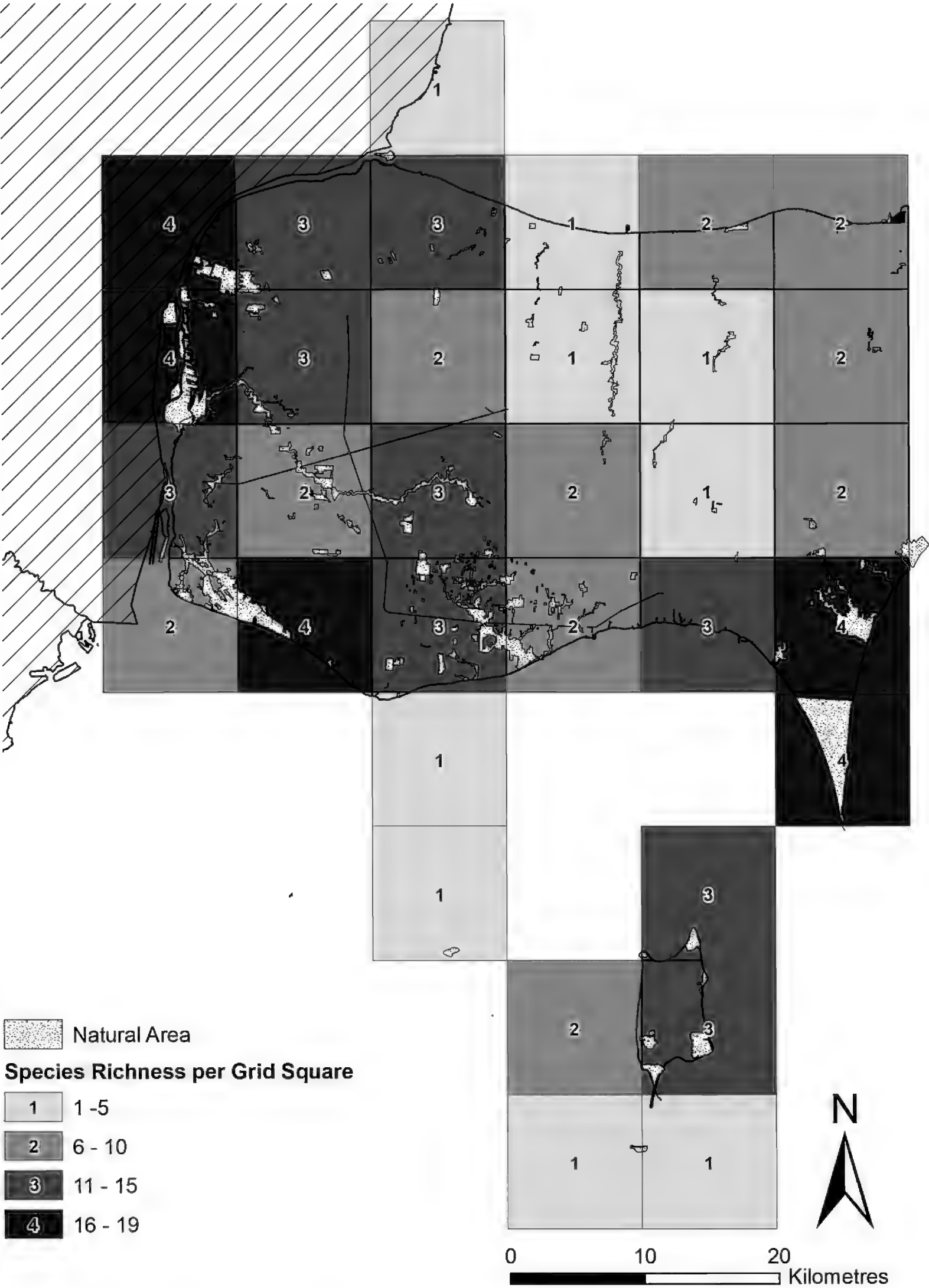


FIGURE 3. Observed herpetofaunal species/subspecies richness per grid square in Essex County, Ontario. See Table 1 for description of natural area.

TABLE 1. Data layers merged in a geographic information system to create a ‘natural area’ shapefile, which was subsequently used to estimate amount of ‘natural area’ within each 10 × 10 km grid square in Essex County, Ontario. Boundaries for all ERCA (Essex Region Conservation Authority) layers are approximate, subject to verification by ERCA and subject to change (copyrighted by ERCA: 1983, 1994, 2008, and 2016). LIO = Land Information Ontario.

Data Layer	Source	Year	Description
Environmentally Significant Areas	ERCA	1983, 1994	Refer to Oldham (1983)
Significant Valleylands	ERCA	2008	Refer to Government of Ontario (2005)
ERCA Lands	ERCA	2016	Lands that are owned or managed by ERCA
Areas of Natural and Scientific Interest	LIO	2014	Refer to Government of Ontario (2005)
Provincially Significant Wetlands	LIO	2006	Refer to Government of Ontario (2005)

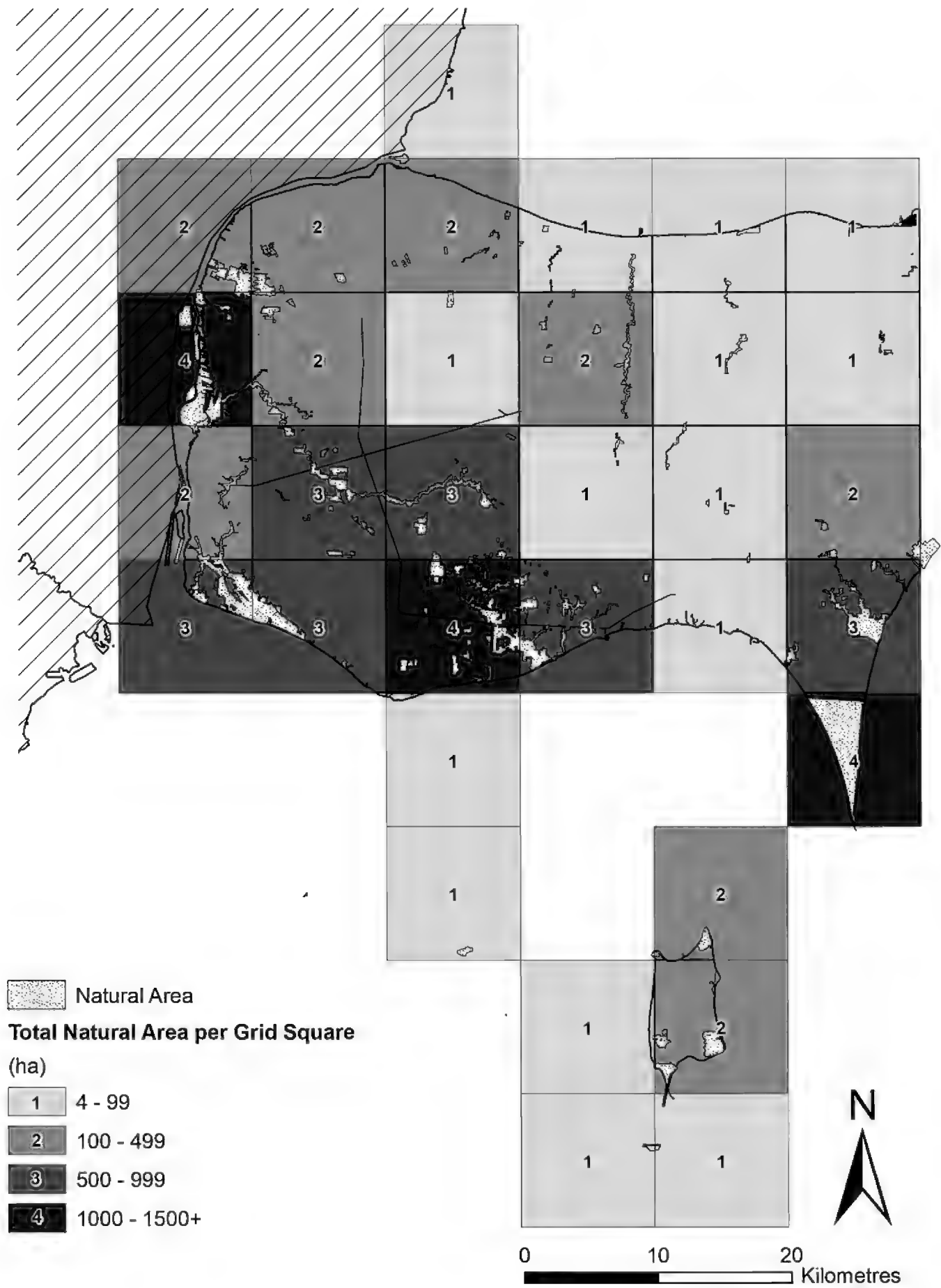


FIGURE 4. Amount of natural area (ha) per grid square in Essex County, Ontario. See Table 1 for description of natural area.

TABLE 2. Historical and current status of the amphibians and reptiles of Essex County, Ontario. IN = introduced species, RE = species considered rare in Essex County, and EE = species considered extirpated from Essex County. Previous (i.e., historical) status retrieved from Oldham (1983). Last observation date, number of recent (i.e., 1997–2016) observations, and number of recent grid squares retrieved from Ontario Nature (2017), unless otherwise specified (‘?’ indicates uncertain or conflicting last observation date or no. of grid squares—see Results for details). Conservation status ranks retrieved from NatureServe (2017), and Ontario ESA (*Endangered Species Act*) status retrieved from Government of Ontario (2018). CP = Carolinian population, TDP = *Ambystoma texanum* dependent population. G = global rank, T = Infraspacific taxon rank (e.g., subspecies), N = national rank. N-ranks displayed are for species or subspecies, not for distinct populations (i.e., designatable units). Conservation status ranks: 5 = Secure, 4 = Apparently Secure, 3 = Vulnerable, 2 = Imperilled, 1 = Critically Imperilled, U = Unrankable, NA = Not Applicable, X = Presumed Extinct/Extirpated. Common and scientific names follow Crother (2017).

Species name	Conservation status rank	Ontario ESA status	Essex County status		Last obs. date	No. recent obs. records	No. recent grid squares (%)
			Previous	Current			
AMPHIBIANS							
FROGS AND TOADS (ANURA)							
Blanchard's Cricket Frog (<i>Acris blanchardi</i>)	G5, NX	EXT	RE	EE	1970s? (COSSARO 2011a)	0	0 (0)
Eastern American Toad (<i>Anaxyrus a. americanus</i>)	G5T5, N5	–	–	–	2016	608	26 (79)
Fowler's Toad (<i>Anaxyrus fowleri</i>)	G5, N2	END	RE	EE	1967 (Ontario Nature 2018)	0	0 (0)
Gray Treefrog (<i>Hyla versicolor</i>)	G5, N5	–	RE	EE	1992 (Ontario Nature 2018)	0	0 (0)?
American Bullfrog (<i>Lithobates catesbeianus</i>)	G5, N5	–	–	–	2015	66	13 (39)
Green Frog (<i>Lithobates clamitans</i>)	G5, N5	–	–	–	2016	198	19 (58)
Northern Leopard Frog (<i>Lithobates pipiens</i>)	G5, N5	–	–	–	2016	313	19 (58)
Wood Frog (<i>Lithobates sylvaticus</i>)	G5, N5	–	RE	EE	1979? (Oldham 1983)	0	0 (0)
Spring Peeper (<i>Pseudacris crucifer</i>)	G5, N5	–	–	–	2016	86	6 (18)
Western Chorus Frog (<i>Pseudacris triseriata</i>)	G5, N4	–	–	–	2016	389	18 (55)
SALAMANDERS (URODELA)							
Blue-spotted Salamander (<i>Ambystoma laterale</i>)	G5, N5	END (TDP)	RE	RE	2015	11	3 (9)
Spotted Salamander (<i>Ambystoma maculatum</i>)	G5, N5	–	RE	EE	1994 (Ontario Nature 2018)	0	0 (0)?
Small-mouthed Salamander (<i>Ambystoma texanum</i>)	G5, N1	END	RE	RE	2015	5	1 (3)
Eastern Tiger Salamander (<i>Ambystoma tigrinum</i>)	G5, NU	EXT	RE	EE	1915 (Ngo <i>et al.</i> 2009)	0	0 (0)
Common Mudpuppy (<i>Necturus m. maculosus</i>)	G5T5, N4	–	RE	–	2016	7	7 (21)
Red-spotted Newt (<i>Notophthalmus v. viridescens</i>)	G5T5, N5	–	RE	RE	2013	5	1 (3)
Eastern Red-backed Salamander (<i>Plethodon cinereus</i>)	G5, N5	–	RE	RE	2016	3	1 (3)
REPTILES							
SNAKES AND LIZARDS (SQUAMATA)							
Blue Racer (<i>Coluber constrictor foxii</i>)	G5T5, N1	END	RE	RE	2016	16	2 (6)
Timber Rattlesnake (<i>Crotalus horridus</i>)	G4, NX	EXT	EE	EE	1930s? (Rowell 2012)	0	0 (0)
Eastern Hog-nosed Snake (<i>Heterodon platirhinos</i>)	G5, N3	THR	RE	EE	1979? (Rowell 2012)	0	0 (0)
Eastern Milksnake (<i>Lampropeltis triangulum</i>)	G5, N3N4	–	RE	EE	1980s? (COSEWIC 2014a)	0	0 (0)
Lake Erie Watersnake (<i>Nerodia sipedon insularum</i>)	G5T2, N2	SC	RE	RE	2016	51	6 (18)?
Northern Water Snake (<i>Nerodia s. sipedon</i>)	G5T5, N5	–	–	–	2016	35	12 (36)
Smooth Greensnake (<i>Opheodrys vernalis</i>)	G5, N5	–	RE	EE	1985 (Ontario Nature 2018)	0	0 (0)
Gray Ratsnake (<i>Pantherophis spiloides</i>)	G4G5, N3	END (CP)	RE	EE	1967 (Ontario Nature 2018)	0	0 (0)
Eastern Foxsnake (<i>Pantherophis vulpinus</i>)	G5, N3	END (CP)	–	–	2016	503	24 (73)
Common Five-lined (Skink <i>Plestiodon fasciatus</i>)	G5, N3	END (CP)	RE	RE	2015	24	4 (12)

TABLE 2. (continued)

Species name	Conservation status rank	Ontario ESA status	Essex County status		Last obs. date	No. recent obs. records	No. recent grid squares (%)
			Previous	Current			
Queensnake (<i>Regina septemvittata</i>)	G5, N2	END	n/a	RE	2016	34	2 (6)
Eastern Massasauga (<i>Sistrurus catenatus</i>)	G3, N3	END (CP)	RE	RE	2015	70	1 (3)
Dekay's Brownsnake (<i>Storeria dekayi</i>)	G5, N5	–	–	–	2016	271	16 (49)
Red-bellied Snake (<i>Storeria occipitomaculata</i>)	G5, N5	–	RE	RE	2016	37	5 (15)
Butler's Gartersnake (<i>Thamnophis butleri</i>)	G4, N2	END	–	–	2016	346	8 (24)
Northern Ribbonsnake (<i>Thamnophis saurita</i>)	G5, N3	SC	n/a	EE	1988? (COSEWIC 2002)	0	0 (0)
Eastern Gartersnake (<i>Thamnophis s. sirtalis</i>)	G5T5, N5	–	–	–	2016	401	25 (76)
TURTLES (TESTUDINES)							
Eastern Spiny Softshell (<i>Apalone s. spinifera</i>)	G5T5, N2	END	RE	RE	2013 (NHIC 2017)	4	4 (12)?
Snapping Turtle (<i>Chelydra serpentina</i>)	G5, N5	SC	–	–	2016	215	22 (67)
Midland Painted Turtle (<i>Chrysemys picta marginata</i>)	G5T5, N4	–	–	–	2016	288	24 (73)
Spotted Turtle (<i>Clemmys gutatta</i>)	G5, N2	END	RE	RE	2013 (NHIC 2017)	5	5 (15)?
Blanding's Turtle (<i>Emydoidea blandingii</i>)	G4, N3	THR	–	–	2016	114	18 (55)
Northern Map Turtle (<i>Graptemys geographica</i>)	G5, N3	SC	–	–	2016	81	15 (46)
Eastern Musk Turtle (<i>Sternotherus odoratus</i>)	G5, N3	SC	RE	RE	2015	17	4 (12)
Woodland Box Turtle (<i>Terrapene c. carolina</i>)	G5T5, NU	EXT	RE	EE	<1900? (COSEWIC 2014c)	0	0 (0)
Eastern Box Turtle (<i>Terrapene carolina</i>)	G5, NU	–	–	IN	–	–	–
Red-eared Slider (<i>Trachemys scripta elegans</i>)	G5T5, NNA	–	–	IN	–	–	–

spread remain widespread today (reported from 6–26 squares [18–79%]; Table 2), whereas one salamander that was previously considered RE is now considered widespread based on recent observations from seven squares (21%) and new research on local abundance and distribution (Detroit River: Craig *et al.* 2015). Five species of snakes are widespread in Essex County, despite two of these being Species at Risk (SAR) in Ontario (reported from 8–25 squares [24–75%]; Table 2). None were previously considered RE. Finally, four turtle species are considered widespread locally, three of which are SAR and none of which were previously classified RE (reported from 15–23 squares [46–70%]).

Rare and extirpated herpetofauna of Essex County

We classified 13 species/subspecies as rare in Essex County (RE; four salamanders, six squamates, and three turtles; Table 2) and an additional 13 species as extirpated from Essex County (EE; four anurans, two salamanders, six squamates, and one turtle; Table 2). A relatively large proportion of salamanders (86%) and squamates (65%) are either extirpated (EE) or limited in distribution (RE), compared to turtles (50% EE/RE) or anurans (40% EE/RE; Table 2). Details regarding changes to Essex County status, questionable last observation dates, and questionable number of recent squares are provided below (in order of taxonomic group).

BLANCHARD'S CRICKET FROG (*Ambystoma maculatum*; EE): Previously RE based on call records from Pelee Island and other locations. COSEWIC (2011) assessed the species as Endangered based on unconfirmed reports from Pelee Island as recently as 1997 and the “miniscule” chance that a very small population persists. Regardless, it has been considered extirpated from Ontario (Hecnar and Hecnar 2005; COSSARO 2011a; Ontario 2018) and we consider it EE.

FOWLER'S TOAD (*Anaxyrus fowleri*; EE): Previously RE based on the possibility of it persisting undetected at one or two locations in Essex County (e.g., Big Creek sub-watershed), despite being considered extirpated from PPNP and Pelee Island. We now consider it EE based on a lack of observations in 50 years and expert opinion (COSEWIC 2010a).

GRAY TREEFROG (*Hyla versicolor*; EE): Previously RE based on observations from Pelee Island. Additional historical sightings were reported from Windsor (EL 1976) and the PPNP area (Hecnar and Hecnar 2004; Ontario Nature 2017). We now consider the species EE based on expert opinion (Pelee Island: King *et al.* 1997; PPNP: Hecnar and Hecnar 2004), and a 25 year absence of records despite recent herpetofaunal surveys at historical locations (COSEWIC 2010b; Gardner-Costa *et al.* 2013) and 20 years of county-wide amphibian call surveys (Tozer 2016). We presume recent observations of single individuals from three disjunct squares (R. Jones unpubl. data) are vagrants (e.g., via nursery stock: Livo *et al.* 1998) as opposed to members of res-

ident breeding populations (following King *et al.* 1997; IUCN 2012).

WOOD FROG (*Lithobates sylvaticus*; EE): Previously RE based on unverified records from OPC and four dispersed conservation areas. Verified historical (or recent) records of this species are absent for the county (e.g., King *et al.* 1997; Hecnar and Hecnar 2004; Tozer 2016; Ontario Nature 2017). Regardless, its confirmed current or historical presence in all adjacent counties (i.e., Chatham-Kent [Ontario Nature 2017], Wayne [MIHerp Atlas 2017], and Erie/Ottawa [King *et al.* 1997]), implies a contiguous historical range that included Essex County.

SPOTTED SALAMANDER (*Ambystoma maculatum*; EE): Previously RE based on records from only two private woodlots in the Hillman Creek sub-watershed. No recent records exist, although it may have escaped detection on private lands. Regardless, we presume this species to be EE based on a high number of recently submitted observations (Figure 2) from the sub-watershed with historical records (i.e., 17LG75 in Figure 1) coupled with a lack of detection.

EASTERN TIGER SALAMANDER (*Ambystoma tigrinum*; EE): Previously RE based on presumed presence at Pelee Island and extirpation from PPNP. Authorities now suggest that the historical presence of this species in Ontario is based entirely on a single accepted specimen reportedly collected from PPNP in 1915 (Hecnar and Hecnar 2005; Ngo *et al.* 2009).

TIMBER RATTLESNAKE (*Crotalus horridus*; EE): Previously EE based on historical observations from Pelee Island (the lone 1918 sighting from PPNP was presumed to be a vagrant from the western Lake Erie Islands). Although some authors consider the historical Pelee Island records to be questionable (King *et al.* 1997) or invalid (Environment Canada 2010), others (following detailed assessments) conclude that there is sufficient evidence of its former presence on Pelee Island (COSEWIC 2001; COSSARO 2011b; Rowell 2012).

EASTERN HOG-NOSED SNAKE (*Heterodon platirhinos*; EE): Previously RE based on records from two locations (OPC and PPNP; see Dance and Campbell 1981) and its presumed extirpation from Pelee Island. We now consider it EE based on a lack of recent observations (one 2001 observation record from Pelee Island is presumed to be erroneous) and expert opinion (King *et al.* 1997; Hecnar and Hecnar 2004; COSEWIC 2007; Rowell 2012).

EASTERN MILKSNAKE (*Lampropeltis triangulum*; EE): Previously RE based on observations from the Cedar Creek and Big Creek sub-watersheds and presumed extirpations from PPNP and Pelee Island. Some historical observations, however, may represent misidentifications (Rowell 2012). We now consider it EE based on a lack of recent verified records and expert opinion (King *et al.* 1997; Hecnar and Hecnar 2004; COSEWIC 2014a).

LAKE ERIE WATERSNAKE (RE): Previously RE based on observations from three Lake Erie islands, including Pelee Island. Although recent observations exist from six squares (18%; Table 2), we consider it RE because its contemporary range includes only three or four freshwater islands (COSEWIC 2015), one of which (Middle Island) straddles the boundary line between two squares otherwise dominated by open water.

SMOOTH GREENSNAKE (*Opheodrys vernalis*; EE): Previously RE based on single specimens reported from two locations (PPNP, grid 17LG74 and Sandwich West Township, grid 17LG27; Figure 1). Few additional historical records exist (Ontario Nature 2017). We now consider it EE based on a lack of records in over 30 years and substantial search effort at historical locations (Figure 2).

GRAY RATSNAKE (*Pantherophis spiloides*; EE): Previously RE based on unconfirmed reports from PPNP and Pelee Island (but see Rowell [2012] for further evidence of historical presence in Essex County). We now consider it EE based on a lack of recent observations and expert opinion (Hecnar and Hecnar 2004; Rowell 2012).

QUEENSNAKE (*Regina septemvittata*; RE): No previous Essex County status. The first confirmed observation in Essex County did not occur until the mid-1980s (see Oldham 1986).

NORTHERN RIBBONSNAKE (*Thamnophis saurita septentrionalis*; EE): No previous Essex County status and no recent records (Rowell 2012). The few historical records appear to be data deficient (e.g., King *et al.* 1997), of questionable validity (e.g., DCL 2009), or conflicting in nature (e.g., records in COSEWIC [2002, 2012] and Ontario Nature [2017]). Regardless, its current or historical presence has been confirmed in many adjacent or nearby counties (i.e., Chatham-Kent [Ontario Nature 2017], Oakland [MIHerpAtlas 2017] and Erie/Ottawa [King *et al.* 1997]), implying a contiguous historical range that included Essex County.

EASTERN SPINY SOFTSHELL (RE): Previously RE and “probably declining” (Oldham 1983), based on observations from PPNP and three other general areas (Pelee Island, Lake St. Clair, and Lake Erie). Still considered RE, however, additional verified reports not included in Table 2 (i.e., not in NHIC database: Hecnar and Hecnar 2004; T. Preney unpubl. data) suggest this species might be widespread.

SPOTTED TURTLE (RE): Previously RE based on known occurrences at four locations. Spotted Turtles have declined from most of their historical Essex County range (Oldham 1983; Hecnar and Hecnar 2004; COSEWIC 2004, 2014b). Recent observations of single animals from three out of five squares (Table 2) may not represent resident populations (i.e., released animals or vagrants: T. Preney unpubl. data), suggesting actual distribution is smaller than reported.

WOODLAND BOX TURTLE (*Terrapene carolina carolina*; EE): Previously RE based on observations at four

locations. While some authors maintained the possibility of a remnant native population in Essex County (Oldham 1983; King *et al.* 1997), recent studies suggest that all 20th century observations are the provenance of released pets (COSEWIC 2014c; see below). We consider it EE as per expert opinion (COSEWIC 2014c; COSSARO 2015).

Introduced herpetofauna of Essex County

Two turtle species are classified as introduced based on recent and historical observations in Essex County and evidence suggesting both can overwinter and reproduce in Ontario.

EASTERN BOX TURTLE (*Terrapene carolina*): Based on genetic analyses, both subspecies of Eastern Box Turtle have been reported from Essex County: *T. c. carolina* (Woodland Box Turtle; historically native to Ontario, see above) and *T. c. triunguis* (Three-toed Box Turtle; native to the south-central United States; COSEWIC 2014c). Most Ontario sightings of this species since 1960 have been from Essex County, including >50 from PPNP (COSEWIC 2014c). Box turtles can overwinter and reproduce in Ontario (COSEWIC 2014c).

RED-EARED SLIDER (*Trachemys scripta elegans*): This species has occurred at the OPC since the 1980s (Oldham 1983; Choquette and Valliant 2016) and at other Essex County locations more recently (Browne and Hecnar 2007; Seburn 2015; Ontario Nature 2017). There is circumstantial evidence that Red-eared Sliders can overwinter in Ontario and successful reproduction is suspected (although not yet established; Seburn 2015).

Herpetofaunal richness across Essex County

Herpetofaunal richness in southern Ontario (Ecoregions 6E and 7E; Armstrong and Dodge 2007) is 47 species/subspecies (excludes nine extirpated, out of range, or non-native species; Ontario Nature 2017). By comparison, contemporary herpetofaunal richness in Essex County is 29 species/subspecies (Table 3), or 62% (29/47) of the southern Ontario species diversity.

The number of recent reptile and amphibian observations submitted per grid square ranged from 1 to 616 (\bar{x} = 128), and the number of species/subspecies reported per grid square (i.e., observed richness) ranged from 1 to 19 (\bar{x} = 9). Grid squares with the lowest observed species/subspecies richness (1–10) dominate the central-eastern portion of the county and the Lake Erie Islands (outside of Pelee Island; Figure 3). Grid squares with the highest observed species/subspecies richness (11–19) occur in the western half of the county, along the north shore of Lake Erie, and on Pelee Island (Figure 3). Furthermore, the five grid squares with the greatest observed species/subspecies richness overall (16–19; Figure 3) are along the western and southern edges of Essex County (17LG28, 17LG27, 17LG35, 17LG75, and 17LG74 in Figure 1). The latter squares include some or all of the following larger natural areas: OPC,

Detroit River Marshes, Turkey Creek Marshes, Canard River Marshes and Canard River Mouth Marsh, Fighting Island Marsh, Big Creek Marsh, Hillman Marsh, and PPNP (ERCA 2001).

The number of herpetofaunal species/subspecies reported per grid square was positively correlated with number of hectares of natural area per square ($r = 0.59$, $n = 31$, $P < 0.001$). Amount of natural area explained a significant, albeit moderate, proportion of variance in observed richness ($r^2 = 0.35$, $F_{1,31} = 16.77$, $P < 0.001$). Additional factors, such as uneven sampling effort (i.e., number of observations submitted) per grid square likely influenced observed richness (see Hortal *et al.* 2007; Pardo *et al.* 2013), particularly in squares with very low number of observations (e.g., 1–15 observations; Figure 2). As expected, observed richness was also positively correlated with number of recent observations submitted per square ($r = 0.68$, $n = 31$, $P < 0.001$). In order to account for effect of uneven sampling on the relationship between natural area and observed richness, we subsequently incorporated sampling effort and natural area in a multiple linear regression. Both the amount of natural area ($\beta = 0.004$, 95% CI = 0.000–0.008, $P < 0.029$) and number of observations submitted ($\beta = 0.013$, 95% CI = 0.006–0.021, $P < 0.001$)

explained a greater proportion of variance in observed richness per square than natural area alone (adjusted $r^2 = 0.51$, $F_{2,30} = 17.63$, $P < 0.001$).

Status of herpetofauna in Essex County

Of the 29 species/subspecies of herpetofauna recognized in Essex County, we consider seven (two SAR) to be the most widespread in the region (i.e., recorded from >18 squares [>55%]) and six (four SAR) to be the most restricted (i.e., recorded from ≤2 squares [≤6%]; Table 2). Furthermore, almost half (13/29; 45%) of extant herpetofaunal species/subspecies in Essex County are limited in distribution (i.e., RE).

Of the 40 native species/subspecies of herpetofauna recognized from Essex County in the early 1980s, only one (3%) was considered extirpated (EE) while 24 (60%) were considered RE (Oldham 1983). The majority (70%, 28/40) of herpetofauna have not changed in local status since the early 1980s. Most surprisingly, however, more than a quarter (11/40; 28%) of reptile and amphibian species have declined in status—a decline that is entirely represented by species that went from being considered rare (RE) historically to extirpated (EE) today. Currently, we recognize 42 native species/subspecies of herpetofauna in Essex County, 13 (31%) of which are now classified EE, with another

TABLE 3. An updated checklist of the reptiles and amphibians of Essex County, Ontario. IN = introduced species, RE = species considered rare in Essex County, and EE = species considered extirpated from Essex County.

AMPHIBIANS (17 species)	
FROGS AND TOADS (ANURA) — 10 species	
<div><div></div><div>Blanchard’s Cricket Frog (<i>Acris blanchardi</i>) EE</div><div>Eastern American Toad (<i>Anaxyrus a. americanus</i>)</div><div>Fowler’s Toad (<i>Anaxyrus fowleri</i>) EE</div><div>Gray Treefrog (<i>Hyla versicolor</i>) EE</div><div>American Bullfrog (<i>Lithobates catesbeianus</i>)</div><div>Green Frog (<i>Lithobates clamitans</i>)</div><div>Northern Leopard Frog (<i>Lithobates pipiens</i>)</div><div>Wood Frog (<i>Lithobates sylvaticus</i>) EE</div><div>Spring Peeper (<i>Pseudacris crucifer</i>)</div><div>Western Chorus Frog (<i>Pseudacris triseriata</i>)</div></div>	
REPTILES (25 species)	
SNAKES AND LIZARDS (SQUAMATA) — 17 species	
<div><div></div><div>Blue Racer (<i>Coluber constrictor foxii</i>) RE</div><div>Timber Rattlesnake (<i>Crotalus horridus</i>) EE</div><div>Eastern Hog-nosed Snake (<i>Heterodon platirhinos</i>) EE</div><div>Eastern Milksnake (<i>Lampropeltis triangulum</i>) EE</div><div>Lake Erie Watersnake (<i>Nerodia sipedon insularum</i>) RE</div><div>Northern Watersnake (<i>Nerodia s. sipedon</i>)</div><div>Smooth Greensnake (<i>Opheodrys vernalis</i>) EE</div><div>Gray Ratsnake (<i>Pantherophis spiloides</i>) EE</div><div>Eastern Foxsnake (<i>Pantherophis vulpinus</i>)</div><div>Common Five-lined Skink (<i>Plestiodon fasciatus</i>) RE</div><div>Queensnake (<i>Regina septemvittata</i>) RE</div><div>Eastern Massasauga (<i>Sistrurus catenatus</i>) RE</div><div>Dekay’s Brownsnake (<i>Storeria dekayi</i>)</div><div>Red-bellied Snake (<i>Storeria occipitomaculata</i>) RE</div><div>Butler’s Gartersnake (<i>Thamnophis butleri</i>)</div><div>Northern Ribbonsnake (<i>T. saurita septentrionalis</i>) EE</div><div>Eastern Gartersnake (<i>T. s. sirtalis</i>)</div></div>	
Salamanders (Urodela) — 7 species	
<div><div></div><div>Blue-spotted Salamander (<i>Ambystoma laterale</i>) RE</div><div>Spotted Salamander (<i>Ambystoma maculatum</i>) EE</div><div>Small-mouthed Salamander (<i>Ambystoma texanum</i>) RE</div><div>Eastern Tiger Salamander (<i>Ambystoma tigrinum</i>) EE</div><div>Common Mudpuppy (<i>Necturus m. maculosus</i>)</div><div>Red-spotted Newt (<i>Notophthalmus v. viridescens</i>) RE</div><div>Eastern Red-backed Salamander (<i>Plethodon cinereus</i>) RE</div></div>	
Turtles (Testudines) — 8 species (+ 2 introduced species)	
<div><div></div><div>Eastern Spiny Softshell (<i>Apalone s. spinifera</i>) RE</div><div>Snapping Turtle (<i>Chelydra serpentina</i>)</div><div>Midland Painted Turtle (<i>Chrysemys picta marginata</i>)</div><div>Spotted Turtle (<i>Clemmys guttata</i>) RE</div><div>Blanding’s Turtle (<i>Emydoidea blandingii</i>)</div><div>Northern Map Turtle (<i>Graptemys geographica</i>)</div><div>Eastern Musk Turtle (<i>Sternotherus odoratus</i>) RE</div><div>Woodland Box Turtle (<i>Terrapene c. carolina</i>) EE</div><div>Eastern Box Turtle (<i>T. c. carolina</i>/<i>T. c. triunguis</i>) IN</div><div>Red-eared Slider (<i>Trachemys scripta elegans</i>) IN</div></div>	

13 (31%) classified as RE. Only one species, Common Mudpuppy (*Necturus maculosus maculosus*), appears to have improved in status.

Discussion

With only 6.5% natural habitat remaining and 80% of the region in agriculture (ERCA 2002), Essex County provides a natural experiment on the impact of landscape-scale habitat loss on an assemblage of herpetofauna. Our results suggest that almost one third of historically occurring species/subspecies are extirpated, and almost half of those remaining are limited in distribution, impacts that have disproportionately affected salamanders and squamates. Furthermore, nine species of reptiles and amphibians that are not at risk in the province (Gray Treefrog, Wood Frog, Blue-Spotted Salamander [*Ambystoma laterale* excluding *texanum*-dependant population], Spotted Salamander, Red-spotted Newt [*Notophthalmus v. viridescens*], Eastern Red-backed Salamander [*Plethodon cinereus*], Eastern Milksnake, Smooth Greensnake, and Red-bellied Snake [*Storeria occipitomaculata*]) are either rare or absent here. In southern Ontario, herpetofaunal species richness was positively related to amount of forest cover (amphibians: Hecnar and M'Closkey 1998), and strongly influenced by proximity of nearby populations (PPNP: Hecnar and Hecnar 2005). Also, the number of endangered species found regionally in southern Canada was positively correlated with intensity of agricultural land use (Kerr and Cihlar 2004). Therefore, the large loss and severe fragmentation of amphibian and reptile habitat that has occurred in Essex County, primarily because of intensive agriculture and an extensive concession-style road network, was probably a leading factor in the landscape-scale defaunation of the region.

Grid squares with the highest herpetofaunal species/subspecies richness (i.e., 17LG27, 17LG28, 17LG35, 17LG74, and 17LG75; Figures 1 and 3) are ideal targets for broad-scale conservation efforts (e.g., habitat restoration and land acquisition), however, not all species are represented in these squares. Of 29 species/subspecies occurring in Essex County, the maximum number reported from any single square was 19 (Figure 3). Even when species/subspecies richness within the five richest squares is tabulated, only 22 species/subspecies are represented. Full representation (i.e., 29 species/subspecies) can be maintained by also targeting conservation efforts within five squares of moderately high richness (i.e., 17LG26, 17LG37, 17LG45, 17LG62, and 17LG63) which are collectively occupied by the six RE species with the smallest distributions (Table 2).

A major assumption of this study is that patterns of observed species/subspecies distributions and richness per square are reliable indicators of true patterns. Sampling effort is clearly uneven among squares, and our

analysis demonstrated that observed richness was influenced by amount of natural area and number of observations submitted. So how reliable are our interpretations? While we acknowledge that observed distributions and richness do not fully represent their true counterparts, we found that the majority of squares with the lowest sampling effort were also those with the lowest amounts of natural area. Therefore additional search effort in those squares (while increasing observed distributions of locally common species and subsequently increasing observed richness therein) is unlikely to alter observed distributional patterns of RE species or relative patterns of observed species richness. The greatest changes in observed richness would be expected from increased search effort in two squares (17LG36 and 17LG25), as both are characterised by relatively high amounts of natural area, low number of submitted observations, and low observed richness, making them ideal candidates for future surveys.

A declaration of local extirpation generally requires various levels of scrutiny, including date of last observation, knowledge of search effort, generation time, etc. In this study we chose a 20-year cut-off as a minimum to classify a species as extirpated from the county. It is possible that an amphibian or reptile species could persist in spite of it not being reported in two decades (e.g., Seburn and Mallon 2017). However, in all but three cases (Gray Treefrog, Smooth Greensnake, and Spotted Salamander; none reported in 22–31 years) each EE species was subject to other levels of scrutiny (e.g., detailed species status reports) prior to being considered extirpated.

To prevent future extirpations in Essex County, recovery efforts should target both SAR and common species that are locally rare because provincial ranks alone do not reflect local status in all cases. For example, five locally widespread herpetofauna are listed as SAR provincially, while four RE species are widespread across southern Ontario (Table 2). Regarding SAR, we've identified seven provincially Endangered herpetofauna with small local distributions (i.e., RE; Table 2) and which are arguably at relatively greater risk of extirpation from Essex County (e.g., Massasauga [*Sistrurus catenatus*] and Queensnake [*Regina septemvittata*]) and Canada as a whole (e.g., Blue Racer and Small-mouthed Salamander). Conversely, provincially widespread species such as the Eastern Red-backed Salamander and Red-spotted Newt are locally rare but not SAR in Ontario, therefore a lack of legal protection could result in further declines and extirpations. Six RE species with the most limited local distributions (three salamanders and three snakes; Table 2) are ideal candidates for targeted conservation interventions (e.g., habitat enhancement, threat mitigation, and population management), in order to prevent further biodiversity loss from this herpetologically significant region of Canada.

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Book Reviews

Book Review Editor's Note: *The Canadian Field-Naturalist* is a peer-reviewed scientific journal publishing papers on ecology, behaviour, taxonomy, conservation, and other topics relevant to Canadian natural history. In line with this mandate, we review books with a Canadian connection, including those on any species (native or non-native) that inhabits Canada, as well as books covering topics of global relevance, including climate change, biodiversity, species extinction, habitat loss, evolution, and field research experiences.

Currency Codes: CAD Canadian Dollars, USD US Dollars, EUR Euros, AUD Australian Dollars, GBP British Pound.

BOTANY

Carnivorous Plants: Physiology, Ecology, and Evolution

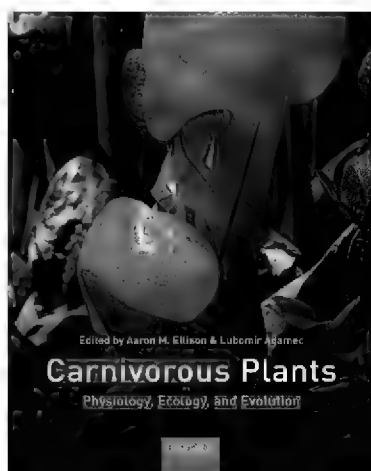
Edited by Aaron M. Ellison and Lubomír Adamec. 2018. Oxford University Press. 510 pages, 125.00 CAD, Cloth. Also available as an E-book.

When *Carnivorous Plants: Physiology, Ecology, and Evolution* arrived on my doorstep, I knew by its heft that this would not be a light read. As a review of the most up to date research on carnivorous plants, this is ideal for senior undergraduate or graduate students, academics, and those with a keen interest in carnivorous plants, but it would be a difficult read if you had no background knowledge in evolutionary biology, botany, or biochemistry. There is a baseline of assumed vocabulary, so if you've never heard the words Diptera, saprophagous, or entomophily, grab a dictionary. In other words: this is a textbook, so plan accordingly.

Editors Aaron Ellison and Lubomír Adamec have done an excellent job of compiling a collection of chapters that represent a range of knowledge in the field, including an overview of the carnivorous syndrome, the evolution of each major genus of carnivorous plant, symbiotic insect and microbial communities, biotechnology and pharmaceuticals, and the mechanisms of prey attraction, retention, and digestion.

Approximately 800 known species of carnivorous plants are found around the world, with hotspots in southeast Asia, Australia, South Africa, and the south-east United States. They grow in a variety of habitats, but thrive in nutrient-poor, warm, and wet conditions. To be truly carnivorous, a plant must display all five of the following traits: capture prey in specialized traps; kill the captured prey; digest the prey; absorb nutrients from the killed prey; and use the nutrients for plant growth and development.

The mechanics of prey attraction, capture, and retention are remarkable. Robert Naczi covers the system-



atics and evolution of my favourite carnivorous plant—*Sarracenia purpurea* (commonly known as the Northern Pitcher Plant or Purple Pitcher Plant, and native to peatlands in eastern North America)—in Chapter 9. As discussed in Chapter 12, contrasting red and green stripes called “nectar guides” attract prey to the lip of the pitcher, along with olfactory cues. Downward facing hairs on the interior guide the prey to the water-filled bottom, where most insects die by drowning. Although the liquid is mostly collected precipitation, death comes faster in a pitcher plant than in pure water—possibly because of the addition of digestive enzymes, and other animals that live in the pitcher plant that help to break-down prey (more on that later).

One of the interesting contradictions of carnivorous plants is that they are almost all entomophilic (pollinated by insects). These are plants that have evolved to attract and trap insects for prey, and yet they rely on insects for survival of the species. Cross *et al.* (Chapter 22) explain that pollinator-prey conflict is rare, owing perhaps to several adaptations, including physical space between the flower and the trap, temporal space between the time of pollination and the time of trap maturation, and different scents emitted by different parts of the plant, designed to attract different insects.

I am fascinated by carnivorous plants and their mutualistic relationship with certain arthropods. I first learned about the Pitcher Plant Mosquito, *Wyeomyia smithii*, while reviewing *The Secret Life of Flies* (Bocking 2017). The female lays eggs in the water of the pitcher, where the mosquitoes hatch and live their entire larval lifecycle, living off the decomposing prey and resident bacterivores and microbes. The trap of a pitcher plant is home to an entire food web that helps the plant break down prey so the plant can more easily absorb its nutrients. The life of *W. smithii* in *S. purpurea* is the most studied relationship of a carnivorous plant and its inquiline (an animal that lives in the living space of another) but, as is discussed in detail in Chapter 24,

most carnivorous plants are host to several species of invertebrates, microbes, and bacteria. We may think about the complexity of the hairs on a sundew, but this is just the surface: there are entire communities of organisms living on, within, and amongst these astonishing plants.

Until recently, the conservation status of only 10% of carnivorous plants was understood. Now we have a basic understanding of about 70%, but there is still work to do. In particular, it's difficult to model how these plants will adapt to a changing climate. Their habitats are diverse and widespread, but it is likely that the availability of suitable habitat will decrease faster than new habitat will become available. Fitzpatrick and Ellison conclude in Chapter 28 that one of our best assurances against species loss is habitat protection. In

Canada, we must protect our wetlands, where most carnivorous plants are found.

This is not a book of fast, easy facts, but it does reward the careful and thorough reader who is passionate about botany. The next time you walk by a sundew, bladderwort, or pitcher plant in your local wetland, you might find yourself with some questions about how these crazy organisms even exist. If you're curious, spend some time with those plants, and with this book.

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EMMA BOCKING

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ENTOMOLOGY

Amazing Arachnids

By Jillian Cowles. 2018. Princeton University Press. 328 pages, 45.00 USD, Cloth, 35.00 USD, E-book.

Amazing Arachnids graced my desk unopened for several weeks while I assumed, based on the title and eye-popping cover, that the book would be a photographic tour of the more spectacular spiders, scorpions, and their kin. That, of course, would have been enough in itself but, when I finally dove into the book, I found it to be much, much more. *Amazing Arachnids* is a thorough treatment of the entire class Arachnida, packed with stunning photos (mostly by the author) and replete with original observations and insights, all stitched together by carefully crafted and densely packed text. I'm not an arachnid specialist, but I found her treatment of even the most obscure arachnid subgroups to be original, readable, and richly detailed.

The first chapter brought me up to speed on basic arachnid structure, biology, and classification in an extensive and exhaustively illustrated introduction, including nice summaries of such disparate subjects as reproductive strategies, fossils, hunting strategies, phylogeny, and vision. The photographic pages covering the "arachnid orders at a glance" (pp. 24–25) were especially useful as an informative snapshot of the orders to be covered in colourful detail in the following pages.

The next nine chapters deal with arachnids other than spiders. Every chapter, even those dealing with relatively obscure groups such as short-tailed whipscorpions and microwhipscorpions, reflects the same level of meticulous scholarship and photographic acumen, with



excellent photographs supporting almost every one of the remarkable bits of behaviour and morphology detailed for every group. The author has clearly spent years finding and carefully photographing not only every taxon, but also the details of hunting, habitats, sexual behaviour, and even minute structures such as spermatophores. It is perhaps not surprising that the lively narrative and associated photographs bring scorpions to life and absorb the reader into the history, biology, taxonomy, and structure of these spectacularly armed arachnids. But she succeeds, impressively, in doing the same for the less familiar pseudoscorpions, vinegaroons, short-tailed whipscorpions, tailless whipscorpions, microwhipscorpions, harvestmen, wind spiders, and even ticks and mites. Each order is exposed as beautiful and full of surprises.

The remainder of the book, including somewhat more than half of its 328 pages, covers the spiders. Chapter 11 introduces the order Araneae and offers fascinating detail about sociality, silk, sex, and special behaviours. Oddly, it does not include a section on spider classification or phylogeny. I would have found a summary hierarchical classification or family tree useful to prepare me for the family-by-family coverage in the subsequent chapters. Chapter 12 begins that coverage with the tarantulas, trapdoor spiders, and other "mygalomorphs", including nine richly illustrated pages each for the tarantulas and the trapdoor spiders, and shorter sections for the less familiar families. Chapter 13 covers three families of orb weavers, while Chapter 14 includes half a dozen families of "irregular web builders". One of these families, the black widow family Theridiidae, is clearly a favourite of the author, as her treatment of this group is full of first-hand insight and especially origi-

nal photos (although this does not mean short shrift for the pholcids and other families discussed in this chapter). Chapter 15 covers the variety of families considered to be crevice weavers, ground weavers, and sheet web builders, with the brown recluse family Sicariidae getting top billing and a particularly readable treatment. Chapter 16 is the most colourful of all, with a good balance of spectacular photos and clear text about everyone's favourite spiders, the Salticidae. The author says that "Jumping spiders have so many pleasing qualities that it would be difficult to decide what is most admirable about these delightful little creatures" (p. 237), but this chapter gives the reader lots on which to base such a decision. The remaining chapters cover the lynx spiders, crab spiders, sand spiders, wolf spiders,

fishing spiders, spitting spiders, and the various families of "wandering hunters". As with the rest of this book, these chapters are illustrated with incredible action photos and detailed shots of taxa and structures. Most of the photos are from the spider hotspots of the American Southwest, and this book could serve as a field guide to Arizona arachnids. But this in no way detracts from its value to Canadian naturalists, because it is an exceptionally readable and authoritative review of Arachnida. I consider this an essential volume for any naturalist with any interest in arthropods.

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Beetles: The Natural History and Diversity of Coleoptera

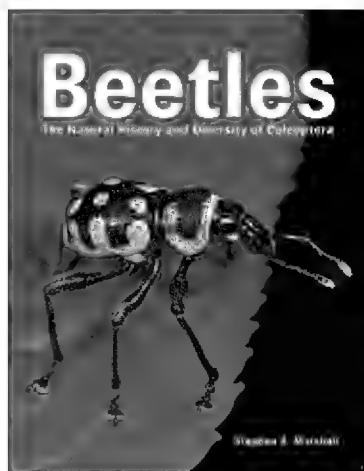
By Stephen A. Marshall. 2018. Firefly Books. 784 pages, 95.00 CAD, Cloth.

A massive work like this book is rarely expected even after a lifetime of study. However, (a) this book has not come out at the end of Marshall's career and (b) this tome is not even his second one, it's his third!

One can open this book anywhere in the almost 800 pages and be met with beautiful photographs of beetles, many of them taken in the field; alone, these would make the book a centerpiece on any naturalist's coffee table. However, the huge volume of information in the text will make this a go-to reference book for even the most ardent coleopterist.

The writing is casual, occasionally humorous (with a mandatory reference to The Beatles!), with scientific jargon kept to a minimum. Having said that, the 'minimum' often includes complex names and processes, simply because no easier words exist. Some zoological background would certainly make the text more digestible to the reader. I would not, however, let this prevent me from gifting this book to an amateur entomologist, nor even a novice.

Part 1 introduces beetle biology (excluding taxonomy), including size diversity, beetle look-a-likes, life histories, and much more. This section is richly illustrated with large, excellent photographs. It is here that we find out why beetles are so successful, both in sheer numbers and diversity. Habitat and food specialists are each given a subsection, as have been defences, pests,



and anatomy. There are more; suffice it to say that I can't imagine a topic which has not been addressed.

Part 2 of this book is a taxonomic look at essentially all of the 180 beetle families. As in his book *Flies* (Marshall 2012), Marshall writes about each family, richly illustrating them with a diversity of species from around the globe; there are over 250 photographs for scarab beetles (superfamily Scarabaeoidea) alone! Again, most of the thousands of shots are of live beetles *in situ*, but some are clearly taken under studio-like settings and a minority are taken of museum specimens (pinned or pointed). There are even photographs of stamps which feature beetles.

The final part of this book is "Studying Beetles". Here, Marshall describes catching, preserving, and photographing beetles. Collecting methods are described, often in detail other authors may have left out. Notes on some legal issues, with an example of those who got into trouble for not following the laws, are described. Finally, the book finishes with a key, richly illustrated, which is very nice. However, and this is literally the only downfall of the book, many of the labelled structures are not magnified enough to be useful.

A book of this quality and magnitude is rare; there should be no second thoughts about getting this for yourself or other insect enthusiast.

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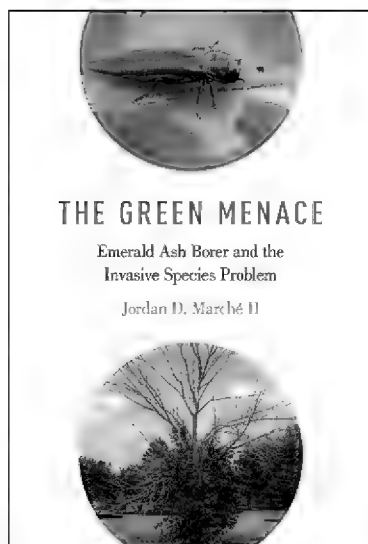
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The Green Menace: Emerald Ash Borer and the Invasive Species Problem

By Jordan D. Marché II. 2017. Oxford University Press. 320 pages, 77.00 USD, Cloth.

Despite its relatively recent arrival, Emerald Ash Borer (EAB; *Agrilus planipennis*) is one of the most destructive invasive species in North America. In little over 20 years, the economic impact of this beetle is estimated in the billions, while its ecological damage is incalculable. *The Green Menace*, by Jordan Marché II, provides a thorough case-study of this invasion, from the first signs of ash (*Fraxinus* spp.) decline detected in Michigan in 1998, the belated attribution of the problem to the EAB in 2002, and through the varied, and largely futile, efforts to eradicate it since then.



For the most part, the book is arranged chronologically. The first chapter reviews what was known about EAB prior to 1998. EAB arrived in Michigan sometime before 1998, but wasn't properly identified until 2002, a period covered in Chapter Two. Chapter Three provides a brief survey of invasion ecology and integrated pest management, and the first steps in developing a government response to EAB. This is followed by two chapters on EAB biology and its social and economic impact. The later stages of the failed effort to eradicate the beetle, or at least contain it to Michigan, are presented in Chapter Seven. More recent efforts to manage EAB with chemical pesticides, biological control, and breeding resistant ash varieties are each explored in separate chapters.

The great strength of the book is the meticulous cataloguing of the historical details of the story. This includes the conventional timeline of the detection of EAB. That is, the first symptoms were detected by Michigan arborists in 1998. They didn't notify plant pathologists (at Michigan State University) until 2001. That led to a tentative diagnosis that the problem was due to a disease called "Ash Yellows". However, the presence of an as-yet-unidentified beetle was also noted. This species, one of more than 2700 in the genus *Agrilus*, was unknown to North American entomologists, and didn't appear in any regional references. Not surprisingly, it took until the following summer before it was properly identified. With that information in hand, authorities were at last in position to initiate control efforts.

However, Marché also documents reports from 1998 documenting ash trees in the area declining as a result of infestation by one or two beetles. At the time, the beetles were suspected to be native species, but identification wasn't confirmed until 2002, as mentioned

above. In effect, EAB had an extra four years to establish and spread. In retrospect, it may have been possible to control it had forceful action been taken in 1998 or 1999. By 2002, it was almost certainly too late—not that we knew it yet.

The chronological presentation of the story highlights the challenges faced by the scientists charged with eradicating EAB. Putting a name on the pest was only the first challenge: nearly nothing was known about its biology or ecology. As with so many noxious invasive species, it is largely unremarkable in its home range, such that it hadn't attracted the attention of Chinese entomologists. There were reports of EAB attacking plantings of North American ash species introduced into China, but they weren't accessible to English-speaking scientists in North America.

In the meantime, it took years to clarify the life history and dispersal potential of EAB. Unfortunately, early data suggested that females could disperse only up to a half mile (0.8 km), and control buffers were established using this figure. As it turns out, this grossly underestimated how far the beetles actually travel. Furthermore, EAB remains difficult to detect for the first two years after arriving in a new location. Consequently, when control efforts started in earnest in 2002 and 2003, EAB had already moved beyond the quarantine zone.

While the central focus of the book is the EAB program managed by the Michigan Department of Agriculture (MDA), it also includes efforts to control the pest in Ontario. Led by the Canadian Food Inspection Agency, an ambitious plan to remove all ash trees from a firewall in southwest Ontario, the so-called "Ash Free Zone", 10 km across and 30 km long, was implemented in 2004 (pp. 111–112). This didn't keep EAB from spreading to the rest of the province, but Marché argues that it was still worthwhile. Despite the public outcry, the ash-free zone may have bought researchers crucial time to develop more robust strategies.

In sum, the first half of the book very effectively presents the challenges posed by invasive species. At a time when seemingly anything you might want to know can be learned by consulting your phone, it is humbling to realize how much about our natural world remains a mystery. Marché has harsh criticism for MDA staff, particularly the opportunities lost in the crucial period between 1998 and 2002. But even had they acted swiftly, and the government provided the requested funding, controlling or eradicating EAB would still have been a formidable challenge.

At this point EAB continues to spread largely unchecked across North America. However, the second half of the book outlines three approaches that may ultimately lead to effective long-term management. Chemical control methods are now available. While they will

never be practicable on a large scale, they may nevertheless provide foresters and landscapers with tools for managing small numbers of important trees. Longer term solution will require a combination of biological control or breeding ash stock resistant to EAB attack.

Overall, *The Green Menace* provides a very insightful case study of the early invasion, establishment, and spread of a serious forest pest. The text does occasion-

ally get bogged down in minutiae. That said, this will undoubtedly serve as an important document for the study of invasive species. I highly recommend it for anyone interested in invasive species, habitat conservation, or large-scale ecological management issues.

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ORNITHOLOGY

Seabird Colonies of British Columbia: A Century of Changes

By Michael S. Rodway, R. Wayne Campbell, and Moira J.F. Lemon. 2017. Wildlife Afield, Volume 13, Numbers 1 & 2, January–December 2016. Biodiversity Centre for Wildlife Studies. 298 pages, 40.00 CAD, Paper.

This book provides a detailed synthesis of knowledge on the distribution and status of 16 species of colonial seabird (two species of storm-petrel, three cormorants, one shorebird, one gull, and nine alcids) that had nested in British Columbia (BC) up to 1990. One additional species has since nested in the province, that being Black-legged Kittiwake (*Rissa tridactyla*). When I began reading this book, I was disappointed to read that the cut-off date for data summaries on these colonial seabirds was 1990 (the last year of focussed surveys and associated comprehensive provincial population estimates by the Canadian Wildlife Service). However, as it turns out, even though the cut-off date for detailed data inclusion is 1990, the book actually contains substantial information for at least some species up to 2015.

The book begins with a tribute to Harry Carter, one of the important contributors to seabird monitoring and research in BC, followed by introductory chapters that provide an overview of how the species for the book were selected, important attributes of BC's coastal environments, the history of seabird monitoring and research in BC, and detailed discussions of survey methods, data presentation, and population estimation. There is some repetition between these introductory sections and the species accounts, but it is useful to have all of the survey history and methodology summarized initially, even if some of those same topics recur in later parts of the book (albeit with different levels of detail).

The heart of the book for most readers will be the species accounts. These occupy roughly a third of the book. Each species account provides general information on the species in BC, as well as sections on appearance, breeding, and conservation. Detailed tabular sum-



maries of numbers of nests/burrows and numbers of birds observed at each colony are provided, accompanied by cartographic summaries showing the relative size of each colony and its location along the coast. One of the interesting additional attributes of each species account (and of other parts of the book) is the sidebar that provides anecdotes about the species, about incidents that occurred during the surveys, or about relevant contributions of some of the surveyors, all of which add to our understanding of these species and the challenges involved in monitoring them. Each species account also is accompanied by a line drawing and usually several black and white photographs of the bird and/or its colonies. These accounts are fascinating and provide insights into each species' biology. For example, although Brandt's Cormorant (*Phalacrocorax penicillatus* [unfortunately misspelled *pencillatus* in the book]) is rather rare and localized as a breeder in BC, numbers build in the late summer from colonies further south along the American west coast, so that the species is relatively common and more widespread on the BC coast during fall, winter, and early spring, before the southern birds return to their breeding colonies.

Following the species accounts, additional chapters cover threats to seabirds and their colonies in BC (including direct exploitation, logging and erosion, man-made obstacles, real estate-associated development, mariculture, commercial fishery interactions, oil pollution, plastics and other pollutants, parasites and diseases, natural predators, introduced species, climate change and associated oceanic changes, and natural disturbances). There is also a section dealing with conservation measures and recommendations. The final part of this book is the Literature Cited section, which is often ignored by readers unless they are searching for a reference. However, in this book, the section is sprinkled with photographs that supplement or further explain the results of some of the papers cited. I really enjoyed reading the captions of these photographs, which add value to the Literature Cited section, in my opinion (an unorthodox approach, but welcome).

There is one subsection in the “Conservation Measures and Recommendations” section dealing with legislation and conservation status listing of species that I disagreed with, particularly with regard to peripheral or range-edge taxa. There are varying opinions as to how such taxa should be dealt with. Although I agree that there may be higher priority species that should be listed before range-edge ones, I do not agree that range-edge populations are not likely to be genetically diverse. No evidence is provided for this proposition, yet, in other groups of organisms (e.g., various angiosperms), there is ample evidence that important evolutionary processes occur in range-edge populations. Furthermore, range-edge populations may become source populations for northward colonization as climate changes (not necessarily a reason for listing, but certainly a reason for certain types of conservation action).

When reading this book, it is important to remember that the context for the species accounts and discussion is BC-focussed. For example, observers on the coasts in

the Maritime Provinces might be bemused by the suggestion that Double-crested Cormorant (*Phalacrocorax auritus*) could be called “Freshwater” Cormorant; certainly, it is the cormorant most likely to breed on freshwater bodies, but by no means exclusively. Another BC seabird-centric comment that would not hold true in many oceanic regions of the world is that “seabirds ... are easy to ... identify compared to other marine species ...” (p. 220).

Overall, I found this book to be an excellent in-depth account and summary of the breeding occurrence and status of the 16 seabird species that nested in BC up to 1990. I did find a number of typographical errors and an occasional missing word but, all in all, these do not detract from the value of the book. For anyone interested in seabirds in general, or for breeding birds of BC specifically, this book is well worth reading.

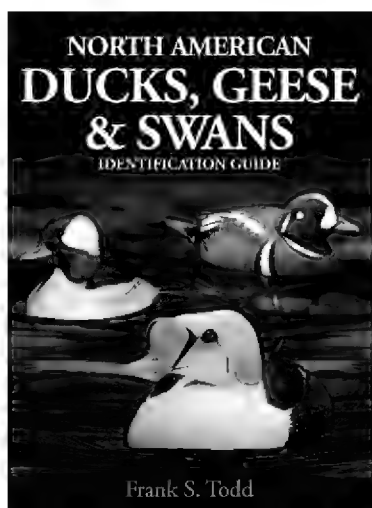
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North American Ducks, Geese & Swans Identification Guide

By Frank S. Todd. 2018. Hubbs Seaworld Research Institute. Distributed in Canada by Hancock House Publishers. 203 pages, 29.95 USD, Paper.

This is a visually stunning book, with superb photographs of each species in a variety of behavioural postures and flight angles, plumages, and age classes; for example, I counted 40 images for Common Merganser (*Mergus merganser*) alone (pp. 167–170). There is very little text: a short preface,



an introductory page to each section (whistling ducks, geese, swans, perching ducks, dabbling ducks, pochards, eiders, sea ducks, stiff-tailed ducks, and “urban” waterfowl, which includes escaped or released exotics), the length, wingspan, and weight of each species, along with a bulleted list of key plumage characteristics and a statement about population size. Each species account also includes a small range map at varying scales. An appendix gives the body mass, number and colour of eggs, incubation time, and number of days from hatching to fledging for each species. The author stretches the definition of North America (usually Canada, the USA, and Mexico) to include the Caribbean, Greenland, the Hawaiian Islands, and United States territories in the Pacific (the Marianas and Aguigan islands). When you include subspecies, Eurasian vagrants, and accidentals, this book covers some 125 “forms”.

While the photographs are excellent, they are not consistently labelled with sex and/or age, and there is no definition of the terms that are used, such as fledgling, juvenile, immature, young, subadult, and first year juvenile, which overlap and can be confusing. And I assume that a summer male is the same as an eclipse male? The Hawaiian Duck (*Anas wyvilliana*) account (pp. 80–81) nicely shows three different age classes of ducklings (at 10, 22, and 72 days), but most other accounts only have one photo with no age indicated. More age-specific labels for other ducklings would have been useful.

There are no source references for population size estimates nor for conservation status (given as stable, increasing, or decreasing) so it is difficult to assess how accurate these numbers are. For example, the population size for “Northern” Mallard (*Anas platyrhynchos platyrhynchos*) is given as ca. 20 000 (p. 69), which must be missing a few zeros. Some statements are confusing, such as when the population size for “Greenland” Mallard (*A. p. conboschas*) is given as ca. 15 000–30 000, followed by “but recent estimates of ca. 100 000” in parentheses (p. 71)—does this mean the author believes the lower range to be more accurate? Some species accounts include both a North American and a global population estimate, while others have only one, even though those birds also breed or winter outside of North America (also the case for the range maps). Other accounts just refer to “population size” without specifying geographic extent.

There are some major errors in the range maps. Having studied Harlequin Ducks (*Histrionicus histrionicus*) for over 20 years, I naturally checked that account first, and discovered that the entire inland breeding range for western North America is missing on the range map (p. 133). And while Greenland is shown on the map, it does not indicate any presence of Harlequin Ducks there, which there are, including birds which migrate from Labrador, Quebec, and Nunavut after breeding (COSEWIC 2013). Conversely, the Tundra Swan (*Cygnus columbianus*) range map (p. 46) only shows breeding range but no wintering range. Considering that waterfowl undertake such spectacular migrations, with abundant numbers seen at stopover sites, some indication of migration routes on the range maps would have been helpful, especially for beginning birders.

There is no indication what audience the author was aiming for; perhaps he simply wanted to showcase a lifetime of waterfowl photography in a book. Todd died before the book was published, and it was completed by three friends, which may have contributed to some of the inconsistencies. While it works as an identification guide, do not buy this as a field guide, but rather as more of a coffee table book that you browse through for the truly excellent photos unlike those in any other book.

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The Birds of Nunavut, Volume 1: Nonpasserines, Volume 2: Passerines

Edited by James M. Richards and Anthony J. Gaston. 2018. University of British Columbia Press. 820 pages, 805 colour photos, and 155 maps, 125.00 CAD, Cloth or PDF, 150.00 CAD, Cloth and PDF.

The Birds of Nunavut is a beautiful and comprehensive two-volume tome that documents the current and historical knowledge of birds known to occur within the territorial boundaries of Nunavut. This is a work of very considerable effort and integration involving 18 co-authors, 805 stunning colour photos, and 155 maps. The Foreword by Jason Akearok, Executive Director of the Nunavut Wildlife Management Board, grounds the effort with a holistic and interactive Inuit perspective on birds, wildlife, environment, and conservation. I have had the double opportunity of working with UBC Press when the manuscript was in production and of now reviewing the finished product.



at 499 pages. Passerine accounts are laid out in Volume 2. For species that breed in Nunavut, each account opens with a synopsis of the species' range and general characteristics, a territorial distribution map, and sections on Appearance, Subspecies, Distribution, Where to See It, Behaviour, Habitat, Diet and Foraging, Phenology, Breeding, and Canadian Status and Threats. Photographs of species that breed in Nunavut include varied combinations of morphs, sexes, winter-plumaged birds, immatures, juveniles, nests and eggs, and young. For species that do not breed in the territory, sections on Distribution and Occurrence in Nunavut are included with photographs of breeding plumaged adults.

Massive in area, Nunavut, like so many other geographic jurisdictions, has some sharply delineated straight and rigidly angled boundaries; the western borders sever continuous ecological expanses and, hence, avian distributions. Owing to small local human aggregations and to research sites and protected areas that are ecologically distributed over most of the territory, key areas stand out as ornithological information hot-spots. The hottest ones, as expected in terms of diversity and rarity occurrences, tend to be located near southern boundaries (e.g., Akimiski, Charlton, and Twin islands in James Bay). Yet, with huge uninhabited areas and with major active research sites, there is implied excitement of the bird information yet to be tapped.

The Birds of Nunavut establishes a firm benchmark from which expected changes can be gauged and periodically updated with supplemental checklists. The ongoing and incrementing flow of bird knowledge and doc-

Volume 1 overviews the territory's ecology, ornithological history, protected areas, monitoring activity, and anthropogenic and climatic threats. It also details the accounts of non-passerine species and is the larger book

umentation mean that geographic bird compilations, however thorough, are essentially outdated before they are published. Thus it is essential for an endeavour of this nature to offer a way forward. With this consideration in mind at the outset, the editors suggest that new observations be submitted to the Canadian Wildlife Service in Yellowknife or to www.eBird.ca. This approach will go a long way in maintaining real-time as well as long-term information about the birds in Nunavut.

While the two volumes have the dimensions and elegance of coffee table books, species accounts are presented in a compelling identification format. The *Birds of Nunavut* has all the makings of a first rate, high quality field guide—descriptions, image quality, and informative distribution maps. So considering yet another way forward, *The Birds of Nunavut* provides a natural substantial framework for a downsized pocket field guide. The existing components need only be distilled to a smaller more portable format. While it is so much easier to envision such a suggestion than to execute it, the editors and publisher might want to consider such an option. Such effort could bring the identification, occurrence, and distributional information directly into the hands of people in the field, where usage and feedback about the birds of Nunavut could be maximized.

On reviewing the prepublication version of this book for UBC Press and again here, my big disappointment with *The Birds of Nunavut* is its rather matter-of-fact attention to many conservation issues and its relative paralysis in offering constructive possibilities for robust conservation initiatives. The omission and lack of even a mention of the warm water run-offs into James Bay from the massive hydro-electric development in northern Quebec and potential synergisms with a changing ocean is totally baffling. For some time, we have been

well aware of the risks and consequences of these warm freshwater outflows into James and Hudson Bays (e.g., Prinsenberg 1980; Milko 1986), leading to fresher sea water, thinner sea ice, and closing polynyas with major effects on marine birds, mammals, and fishes and resulting consequences for aboriginal people and their communities. While the authors recognize the extreme importance of a wintering aggregation of eiders in a local polynya for the residents of Sianikiluag in the Belcher Islands, they fail to mention that the warm freshwater from the hydro development is causing the polynya to freeze over (<https://arcticeider.com/en/knowledge-solutions/?tab=knowledge§ion=collapseOne#collapseOne>). The game has changed for all of us, and the time for business as usual is over; crisis management is now essential at every step of the way. We have to recognize and address major human-induced threats to wildlife and our environment and offer constructive possibilities to act on them. Otherwise, it is just not going to happen.

I have many geographic bird books in my library—*The Birds of Nunavut* is the best one. Given the nature of the subject in our current pivotal state of changing climate, *The Birds of Nunavut* offers more than just another book about birds; it is an invitation to engage in an ongoing rapidly changing environmental process.

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BILL MONTEVECCHI

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ZOOLOGY

Wildlife of the Arctic

By Richard Sale and Per Michelsen. 2018. Princeton University Press. 304 pages, 19.95 USD, Paperback.

Wildlife of the Arctic provides a good overview of the Arctic environment and many of the animals that live there. The authors are both explorers of the Arctic, with decades of combined experience in the region, which has provided them with unique perspectives on Arctic wildlife. Richard Sale has written multiple books about exploring different parts of the world, including a few about Arctic wildlife. Per Michelsen is an outdoor photographer who has focussed mostly on the Arctic and sub-Arctic.



The preface to the book offers a good glimpse into the intended audience of the book: the authors discuss early Arctic explorers and how the Arctic continues to inspire adventurers. The intended audience is for those interested in exploring the Arctic, from first-time visitors to people exploring new areas of the Arctic. This book will likely not be sufficient for ecologists and more advanced naturalists. Individual species accounts are quite general, the list of species and species accounts is not exhaustive, and no range maps are provided (species accounts typically contain a single sentence about the species range). More taxa-specific guides are recommended for people requiring detailed accounts of species in the Arctic.

The authors begin by describing the physical environment of the Arctic and how animals have adapted to

living there. The authors also spend a few pages defining what they consider to be Arctic. The definition of the Arctic can be ambiguous, sometimes being defined by the Arctic Circle (66.56°N), other times by the tree line, and still other times based on average temperature. These authors decided instead to use their own definition, which they feel the average person would likely agree with. This definition of the Arctic uses the average temperature, but also includes areas that the average person would consider to be Arctic, such as Churchill, Manitoba, and the entirety of Iceland, which are not included by the standard temperature definition.

After setting the stage, the authors then spend most of the book describing Arctic wildlife with species accounts of birds and mammals, including marine mammals, illustrated by many very nice photographs, followed by a small section describing the general variety of ecosystems, invertebrates, fungi, and plants found in the Arctic. Within the species accounts, the authors typically provide nearly a page of information about each group of species (e.g., ducks, eagles, rodents, ungulates), but then vary the amount of information that they provide for individual species. Some species accounts are only a couple of sentences (e.g., Siberian Brown Lemming [*Lemmus sibiricus*]), while others span a half page (Arctic Ground Squirrel [*Urocitellus parryii*]) or more than a page (Reindeer/Caribou [*Rangifer tarandus*]). The amount of information provided for each species is not a function of what is known about the species, but more likely related to how familiar the authors are with these species or to the more “iconic” species that Arctic travellers are likely to encounter and possibly care more about. For example, raptor species (e.g., eagles, hawks, and falcons) have nearly a page devoted to each of them, whereas waterfowl have a quarter of a page. Some species of mammals didn’t receive species accounts: there is a single page on shrews, but no individual species accounts, unlike with other groups.

The authors do not provide species accounts for amphibians, reptiles, and fish, although they mention amphibians and reptiles found in the Arctic in the section on how wildlife have adapted to cold environments, and they mention fish when discussing Arctic ecosystems. There is no explanation provided for why these species are excluded, but it is likely related to which species will be seen most by Arctic explorers. However, a section on fish species that are important to Arctic people, such as Arctic Char (*Salvelinus alpinus*), would have been useful for first-time visitors of the Arctic.

The common names used for species are generally European, which may be confusing for readers from North America. The authors usually list the European name first with the North American name in parentheses (e.g., “Red-throated Diver (Red-throated Loon)”). In some cases, however, they don’t acknowledge the North American name this way; for example, “Common Merganser” is listed simply as “Goosander”, with a statement in the description that it is “occasionally called Common Merganser”. In other cases, the authors first state the North American name with the European name in parentheses (e.g., “Moose (Elk)”). More consistency in the treatment of European versus North American names is needed, and a few sentences in the introduction describing how different names are denoted would have been useful.

Overall, this book will be a useful general introduction to Arctic wildlife for travellers who have an interest in the topic. However, for details about specific groups of species, readers should look to taxa-specific guides.

WILLIAM D. HALLIDAY

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Guide to the Parasites of Fishes of Canada Part V: Nematoda

By Hisao P. Arai and John W. Smith. Edited by Michael D.B. Burt and Donald F. McAlpine. 2016. Zootaxa 4185, Magnolia Press. 274 pages, freely available (<https://biotaxa.org/Zootaxa/article/view/zootaxa.4185.1.1>), PDF.

Over the last four decades, the parasites impacting Canadian fish species have been described in Volumes I–IV of the *Guide to the Parasites of Fishes of Canada*, with *Part V: Nematoda* by Hisao P. Arai and John W. Smith bringing much needed attention to the parasitic nematodes affecting Canadian fishes. Nematodes occupy nearly every habitat from soil to sea and are recognized as one of the most abundant multicellular animals on earth. Parasitic nematodes of fishes can pose a threat not only to fish health but also to the organisms (including humans) that consume these infected hosts, emphasizing the urgency to study this group of organisms.

This volume is first and foremost an identification key for the nematode parasites of Canadian fishes, pro-

viding detailed information on all taxonomic levels. The taxonomy follows the broader taxonomic guides on nematodes of vertebrates while incorporating research discoveries made in recent decades. Species are described that have only just gained recognition in recent years, despite having negative economic consequences (e.g., *Huffmanella canadensis*, *Philometra rubra*, and *Anguillicola crassus*). The book is remarkably thorough, compiling information from an expansive reference list of over 800 citations, which is reflected in the level of detail in each key.

The keys and descriptions cover 88 species, spanning 47 genera expertly described by the authors. These keys provide a concise yet detailed description of each listed

taxon. Each species or taxonomic rank includes a morphological description, reported hosts, host anatomical site, geographical distribution, and previous literature records. This information is coupled with over 100 detailed illustrations that present nematode anatomy in a way that cannot often be appreciated within photographic images. These illustrations provide the reader with views of organisms in their entirety, and views of specific anatomy relevant to species identification. Fish parasitologists will benefit from details provided within the introduction on the procedures and protocols used to collect, examine, and identify nematodes from fish hosts. Although these components of the book will be most relevant to experts within the field, broader information on Phylum Nematoda, nematode morphology, and the geographical distributions of nematodes can be gleaned by readers lacking familiarity with this area of research. The indices by nematode and fish species are particularly valuable for readers seeking species-specific

information. These indices will be useful for fisheries biologists looking to understand which nematode species may be present in a target population, based on their potential hosts and geographical distributions.

The authors make it clear that morphology-based identification is still a major component of nematode taxonomy, and that molecular-based taxonomic information is lacking for most species. This book should serve as a call to action for further attention into nematode phylogenetics, as a greater understanding of their taxonomy may benefit fish and human health alike. Despite focussing primarily on Canadian parasitic nematodes, these nematode species affect fishes from around the world, highlighting the value of this guide to a global readership.

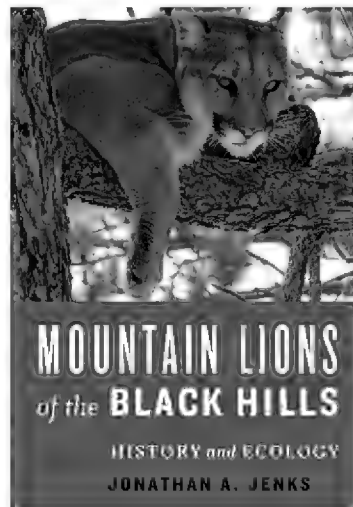
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Mountain Lions of the Black Hills: History and Ecology

By Jonathan A. Jenks. 2018. Johns Hopkins University Press. 160 pages, 75.00 USD, Cloth or E-book.

I have always had a childhood fascination with Mountain Lions (*Puma concolor*) and a recent narrative I read of a lion travelling from South Dakota to Connecticut got me very interested in learning more about its origins (Way 2017). And so, it was with good fortune that I was able to find it here with *Mountain Lions of the Black Hills*.



The book was an enjoyable read and is a valuable contribution to North America's predatory fauna. Mountain Lion is a cat with many names: Cougar, Puma, Catamount, Panther, and Deer Tiger, among others. Their large range once included virtually all the lower 48 United States from coast to coast, but by the 1960s they were reduced to small populations in the western United States and a token population in south Florida. In *Mountain Lions of the Black Hills*, author Jonathan Jenks describes his research team's experiences and findings from over 200 of these amazing animals, radio-tracked as they returned to a portion of the northern Great Plains in western South Dakota.

Jenks has an easy-to-read style where each chapter is written like a stand-alone scientific manuscript with a complete Literature Cited section at the end. Each bibliography cites peer-reviewed articles and graduate theses/dissertations, many from his own students.

However, chapters contain simplified enough language to make it readable for the layman and each chapter smoothly flows from one to another as he reports on Mountain Lion ecology, characteristics (e.g., body size and distribution), diet, population dynamics, disease ecology, nutrition, behaviour, and genetics. I particularly liked the sections on dispersal (e.g., pages 57–59) showing how far young Mountain Lions can travel when they leave their mother's territory. Jenks provides very interesting discussion on how that population of lions is connected to others in Wyoming, Colorado, and North Dakota.

Jenks explores a population that was just recolonizing the Black Hills in the late 1990s yet quickly saturated the area within about 10 years. His research examined the impact of a changing prey base on population growth then decline as lions went from a protected species to having an established hunting season set on the cats. A theme of Jenks' prose is figuring out how to balance conserving Mountain Lions with the needs of humans.

I found the book to be useful and a great reference for the species as it slowly expands its range eastward, reclaiming territory that had been lost within the past 100–200 years. It is easy to find key information on the species, such as territory sizes for males (300+ km²) and females (66–198 km²), body weights of males (averaging 130–150 pounds, 59–68 kg) and females (90 pounds, 41 kg), litter sizes (averaging 3+), age of dispersal (a relatively young 15 months of age), and population size in the Black Hills (150–250). The book is only 160 pages yet has 57 black and white photos and

15 graphs/tables. I loved all the pictures and thought that it complemented the text perfectly. In fact, I wish more scientifically-oriented books were like this: simple to read, containing concise information, and well-illustrated!

Jenks also explored people's evolving perceptions of Mountain Lions and I found that chapter (8) interesting in a few respects. While I enjoyed the book and thought it was well done, I was troubled by the incessant use throughout of the euphemistic word "harvest" (Johns and Dellasalla 2017) and a total lack of discussion about the ethics of killing a sentient large carnivore (Vuchetich and Nelson 2014). Abundant research indicates carnivores are ecologically important, and are social, sentient, family-oriented animals which regulate their own numbers by defending territories (Eisenberg 2014). Sociological research has consistently demonstrated society's decreasing support of lethal control and trophy hunting, especially regarding carnivores (Jackman and Way 2018). So, it was of interest to me that the main findings from Chapter 8—that sociological research supported hunting Mountain Lions in South Dakota—are from government reports which had not apparently experienced peer review. I can't help but think that a pro-hunting stance, which all of these government agencies have, may have biased these documents. Given all of the great data presented throughout the book, Jenks' team could've designed a scientifically rigorous hunting season using similar data and methods as described in Washington State, whereby "harvest thresholds" were established in which no more than 14% of the estimated density of adult resident Mountain Lions could be killed by hunters in relatively small areas to prevent localized over-harvest (see Beausoleil *et al.* 2013). This provision allows some human recreational use of carnivores, but at a level that should not upset the natural social organization, population stability, or immigration of transient Mountain Lions, and at a level that results in low mortality of adult residents. This protection threshold is particularly important given the relatively isolated nature of the population in the Black Hills. Conversely, it appears that the state of South Dakota just willy-nilly picked "quotas" not based on science but rather on perceived public opinion starting with conservative harvests in 2005 and moving to reduce the population in a short amount of time (~ five

years). While Jenks does an admirable job documenting how the population stayed genetically healthy, I couldn't help but think of how carnivore hunting generally favours biased or outdated research over the best available independent science (Artelle *et al.* 2018; Karns *et al.* 2018).

Overall, this is a valuable book. The illustrations make it a valuable reference for wildlife enthusiasts. It was well written with just a few minor errors. The only thing that perplexed me was the high price for a seemingly simple black and white hardcover book. For the life of me, I cannot fathom why it was \$75 USD when it could probably be \$10 USD when printed with a softcover. Otherwise, I can't read enough about Mountain Lions and other large carnivores and dream of the day when a similar type of book is written on a recovered Mountain Lion population(s) here in the northeast United States where I reside!

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JONATHAN (JON) WAY

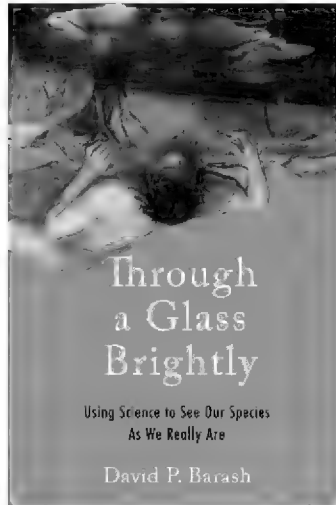
Eastern Coyote/Coywolf Research, Osterville, MA, USA

OTHER

Through a Glass Brightly: Using Science to See Our Species as We Really Are

By David B. Barash. 2018. Oxford University Press. 208 pages, 30.95 CAD, Cloth.

David Barash uses quirky humour, a sprawling compendium of references—from the Bible, to classical writers, to poets and academics new and old, to SpongeBob Squarepants (seriously!)—and succinct recaps of scientific research to put the boots to 15 paradigms that many of us take as pretty much self-evident. An evolutionary



biologist, professor emeritus of psychology, and prolific author, Barash writes knowledgeably and comfortably on such topics as the meaning of life, whether we have unique and separate selves, parent/child conflict, monogamy, the nature of truth, and war and peace. His explorations and explanations of science, especially biology, provide the basis for his iconoclastic approach to the 'common knowledge' positions on these topics. As iconoclasts go, he's very good.

Divided into two sections, the book builds on several of his previous publications, as he notes in nearly every chapter. Each section begins with a prelude, and it's worth repeating their lengthy titles to get the gist of the sections and hence the book. Part I, "The Allure of Human Centrality, or, How We Persistently Try to Deny Our Place in the Natural World – And Fail", brings up to the present the long and ongoing debate, dating back centuries, over the superiority of *Homo sapiens* compared to any other species and the notion that the universe revolves around us. The latter view was held in the Ptolomeic world, and its debunking by Copernicus and Galileo took a few centuries to catch on. Similarly, the notion that we are the centre of our psychological universe, with nature—seen as 'outside' ourselves—being there for our use and disposal, more than lingers. We can see it in everything from the 'yuck' response to bugs and spiders to climate change denial/inaction that helps maintain the status quo. Thus, the first order of business in this section is a critical examination of this big-picture myth of human centrality. Barash explores our modocentrism through (among other things) the concept of a 'reverse' world map, then moves on to the question of how we determine the meaning of life in the face of biological purposelessness. He demolishes any self-satisfaction humans may find in the notion that our body plan is well-designed, rejects the notion that human consciousness is necessary for the universe to exist, and notes that, despite our tough talk, many organisms are much tougher than we are. Want to compete with extremophiles, anyone?

More radically, he boldly favours—which is different from advocating!—the cloning of humans and chimpanzees, if only to demonstrate our connectedness to everything, thereby refuting the common belief that only human life is important. The concept of connectedness is used to expose the illusion that self exists independently of everything else. Rather, we are all symbionts, as demonstrated by our bacteria-filled microbiomes.

In Part II, Barash provides "New Ways of Understanding Human Nature". He makes the argument here that human behaviour itself "is altogether natural... woven from the same biological cloth as other living things" (p. 85). The point here is neither the reduction of humans to the level of animals, nor the elevation of animals to the level of humans, but to get rid of the level itself so that we can see our inter-relatedness to all living beings. This shift in thinking, so hard for many to accept, becomes more acceptable if it's seen as "lateral", not "downwards".

The chapters in Part II explore aspects of this, putting under the lens, to provide only several examples, our beliefs in our capacity for thoughtfulness, the inevitability of a generation gap, our ability to distinguish truth and falsity, the problem of morality, and evolutionary theory. Other commonly held views receive this close scrutiny: humans are monogamous, altruism proves our higher nature, humans are natural born killers, and we have free will so are truly 'captains of our fate'. In each instance, Barash seeks to explode the old paradigms, replacing them with science-based concepts that serve us better in our understanding of ourselves and the natural world. Perhaps the most sobering is explored in Chapter 16, "The Paradox of Power". Here, Barash asserts that our cultural capacity to develop weapons outpaces our biological, evolutionary capacity to develop restraints in using them: "We are, via cultural evolution, in over our biological heads" (p. 186).

Each of the myriad topics Barash tackles in this short book could be addressed in books of their own—and often have been, as noted above, in other books of his. Here he is summarizing, it seems to me, a life's work of thinking, researching, and synthesizing. As such, the book is an excellent introduction to topics that are worthy of the reader's further exploration. While Barash's tone often disguises the serious purpose behind the book, that purpose is clearly laid out in his concluding remarks: to help us see ourselves as we really are. In other words, his purpose is to provide fresh paradigms that enhance our understanding of human behaviour and, through that, our sense of responsibility for the quality of our lives, and the world we live in.

The two introductory preludes set up each section; chapters therein are short, with brief references cited in endnotes after each chapter. The book is indexed but does not have a bibliography. Other writers have written bigger books on these topics. But for a solid, acces-

sible, thoughtful introduction, this is an excellent place to start, recommended reading for anyone interested in these questions.

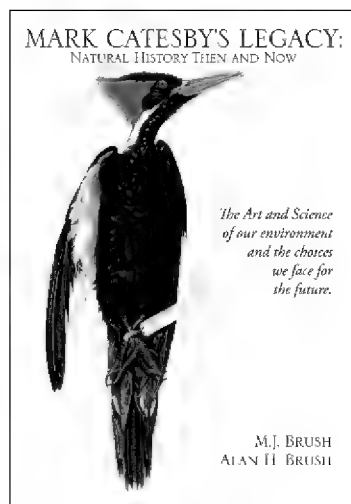
BARRY COTTAM

Ottawa, ON, Canada

Mark Catesby's Legacy: Natural History Then and Now

By M.J. Brush and Alan H. Brush. 2018. The Catesby Commemorative Trust. 191 pages and 32 original watercolour plates, 28.95 USD, Paper.

Catesby's "watercolors ... were his legacy; [they] provided a perspective on nature, history and the environment, ... and an amazing tale of perseverance, exploration and art" (p. 6). They became "the benchmark for the early stage of the age of exploration and discovery in eastern North America" (p. 6). Alan and M.J. Brush



have chosen the perfect time to answer for the reader the question of how much Catesby's world has changed in the centuries since his wonderful depiction of it.

Mark Catesby was born in Castle Hedingham, Essex, 24 March 1683, during the coldest winter in living memory. Mark's first transatlantic voyage to Virginia was as a chaperone for his eldest sister Elizabeth and her two children, sailing to Virginia to rejoin her husband, Dr. William Cocke, where they arrived 23 April 1712. Mark's first principal host was William Byrd II on his James River estate. Catesby travelled widely, visited Jamaica in 1714, then Bermuda, and was mentioned in the *Philosophical Transactions of the Royal Society* in 1715. He regularly sent specimens to interested people in England, then returned to England by mid-October 1719. While in England during 1721, Catesby gained support of sponsors within the Royal Society, enabling him to sail to Charles Town, South Carolina, where he arrived 3 May 1722. He collected birds and plants until he reached the Bahamas early in 1725. He returned to England in 1726. Alan and M.J. Brush were stimulated by the Catesby Commemorative Trust which in November 2012 held a symposium to mark the 300th anniversary of Catesby's first voyage in three centres: Washington, DC, Richmond, Virginia, and Charleston, South Carolina. The symposium resulted in *The Curious Mister Catesby* (Neston and Elliott 2015).

From their home in Connecticut, Alan and M.J. Brush sailed their 330 Cape Dory cutter along the Atlantic coastline, often following the Intercoastal Waterway constructed in 1919 along the North Carolina and Georgia coasts. They then explored shallower waters

between the islands of the Bahamas. "The deck of a small sailboat offers an unprecedented view" (p. 15). One of their reported challenges was to explore the ways plants and animals made their living over the 300 years since Catesby's time, in light of the continually shifting, changing, and often hostile world. With Alan's life-long learning in biology, particularly ornithology, and M.J.'s artistic skills, we have the perfect combination throughout this book, chapter by chapter.

Most readers should find Alan's "brief history" of ornithology informative, but especially the page on the contributions of Linnaeus, who gave each bird and plant a genus and unique species name, which quickly became the world standard. Variations and refinements were contributed by two French scientists, Brisson and Reaumur, followed by the German Blumenbach, and then finally Charles Darwin specified natural selection working on natural variation. Next, Alan details the stories of three bird species declared extinct since Catesby's time, including Passenger Pigeon (*Ectopistes migratorius*), which was seen in aggregations of more than two million birds by Alexander Wilson in 1806, until the final aviary captive died in 1914 after 29 years in the Cincinnati Zoo. Ivory-billed Woodpecker (*Campephilus principalis*) and Bachman's Warbler (*Vermivora bachmanii*) were last seen in 1943 and 1958, respectively.

M.J. provides gorgeous paintings of the plants, the Southern Orange, Southern Magnolia, Franklinia, Catalpa, Carolina Jessamine, Longleaf Pine, Wild Olive, Mountain Laurel, Sheep Laurel, Bog Laurel, Tulip Tree, Empress Tree, Brazilian Pepper-Tree, Morrows' Honeysuckle, Smooth Cordgrass, and fish, such as the Gray Triggerfish, Silk Snapper, Black Sea Bass, Graysby, and Yellow-fin Tuna, as well as Gray Sea Turtle and Caribbean Spiny Lobster.

Alan and M.J. point out the dynamic equilibrium of a salt marsh, with its grasses, snails, and shells, and the role they play for the White Ibis, Scarlet Ibis, Great Blue Heron, Green Heron, Fish Crow, American Oystercatcher, crabs, scallops, and oysters. M.J.'s most recent exciting expedition was as a deep-sea artist in a self-propelled, titanium submersible along the floor of the Atlantic Ocean, where the fish of great depths are beyond the reach of sunlight. These organisms are visible under such conditions because some of the body

appendages of colonial squid and jellyfish are transparent, with photophores that attract prey.

I recommend without reservation this delightful and informative book as a companion for any naturalist visiting the lower Atlantic coast and through the Bahama Islands. It makes a great companion too for the larger, heavier *The Curious Mister Catesby*.

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C. STUART HOUSTON

Saskatoon, SK, Canada

NEW TITLES

Prepared by Barry Cottam

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BOTANY

Michigan Ferns and Lycophytes: A Guide to Species of the Great Lakes Region. By Daniel D. Palmer. 2018. University of Michigan Press. 392 pages, 29.95 USD, Paper.

Mushrooms of the Northeastern United States and Eastern Canada. A Timber Press Field Guide. By Timothy J. Baroni. 2017. Workman Publishing. 600 pages, 27.95 USD, Cloth, 14.99 USD, E-book.

The Allure of Fungi. By Alison Pouliot. 2018. CSIRO Publishing. 280 pages, 49.99 AUD, Paper.

Sex on the Kitchen Table: The Romance of Plants and Your Food. By Norman C. Ellstrand. 2018. University of Chicago Press. 208 pages, 75.00 USD, Cloth, 20.00 USD, Paper, 18.00 USD, E-book.

Floral Mimicry. By Steven D. Johnson and Florian P. Schiestl. 2016. Oxford University Press. 188 pages, 120.00 USD, Cloth, 59.95 USD, Paper.

Tree: A Life Story. Revised Edition. By David Suzuki and Wayne Grady. Foreword by Peter Wohlleben. 2018. Greystone Books. 206 pages, 19.95 CAD, Paper. Also available as an E-book.

Trees in Canada. 100th Anniversary Redesigned Edition. By James Laird Farrar. 2018. Firefly Books. 512 pages, 60.00 CAD, Cloth.

ENTOMOLOGY

Field Guide to the Flower Flies of Northeastern North America. By Jeffrey H. Skevington and Michelle M. Locke, with Andrew D. Young, Kevin Moran, William J. Crins, and Stephen A. Marshall. 2019.

Princeton University Press. 536 pages, 3000 colour plates, and 414 maps, 27.95 USD, Flexibound.

Our Native Bees: North America's Endangered Pollinators and the Fight to Save Them. By Paige Embry. 2018. Timber Press. 40 pages and 104 colour images, 24.95 USD, Cloth.

Where Honeybees Thrive: Stories from the Field. Animalibus of Animals and Cultures, Volume 10. By Heather Swan. 2017. Pennsylvania State University Press. 176 pages, 29.95 USD, Paper.

Butterflies of the Pacific Northwest. By Robert Michael Pyle and Caitlin C. LaBar. Timber Press. 464 pages, 612 colour photos, and 198 maps, 27.95 USD, Flexibound.

The Bee: A Natural History. By Noah Wilson-Rich, with contributions from Kelly Allin, Norman Carreck, and Andrea Quigley. 2018. Princeton University Press. 224 pages, 17.95 USD, Paper. Cloth edition published in 2014. Also available as an E-book.

Insect Behavior: From Mechanisms to Ecological and Evolutionary Consequences. Edited by Alex Cordoba-Aguilar, Daniel Gonzalez-Tokman, and Isaac Gonzalez-Santoyo. 2018. Oxford University Press. 448 pages, 110.00 CAD, Cloth, 54.95 CAD, Paper.

HERPETOLOGY

Peterson Field Guide to Reptiles and Amphibians of Eastern and Central North America. Fourth Edition. By Bob Powell, Roger Conant, and Joseph T. Collins. 2016. Houghton Mifflin Harcourt. 512 pages, 21.99 USD, Paper.

Eye of Newt and Toe of Frog, Adder's Fork and Lizard's Leg. The Lore and Mythology of Amphibians and Reptiles. By Marty Crump. 2015. 304 pages and 155 colour plates, 35.00 USD, Cloth, 21.00 USD, E-book.

Snakes of the World: A Catalogue of Living and Extinct Species. By Van Wallach, Kenneth L. Williams, and Jeff Boundy. 2017. CRC Press (Taylor & Francis Group). 1237 pages, 168.00 USD, Cloth, 64.00 USD, Paper or E-book.

Reptiles of Victoria: A Guide to Identification and Ecology. By Peter Robertson and A. John Coventry. 2019. CSIRO Publishing. 336 pages, 45.99 AUD, Paper.

U.S. Guide to Venomous Snakes and Their Mimics. Reprint Edition. By Scott Shupe. 2019. Skyhorse Publishing. 160 pages, 14.99 USD, Paper.

Atlas of Reptile Development. By Jacqueline E. Moustakas-Verho and Raul Diaz. 2019. CRC Press (Taylor & Francis Group). 300 pages, 119.96 USD, Cloth.

The Maryland Amphibian and Reptile Atlas. By Heather R. Cunningham and Nathan H. Nazdrowicz. 2018. Johns Hopkins University Press. 312 pages, 74.95 USD, Cloth or E-book.

Dreaming in Turtle: A Journey Through the Passion, Profit, and Peril of Our Most Coveted Prehistoric Creatures. By Peter Laufer. 2018. Macmillan Publishers, St. Martin's Press. 304 pages, 28.99 USD, Cloth, 14.99 USD, E-book.

Herping Texas: The Quest for Reptiles and Amphibians. By Michael Smith and Clint King. 2018. Texas A&M University Press. 336 pages and 156 colour photographs, 30.00 USD, Flexibound. Also available as an E-book.

Status of Conservation and Decline of Amphibians: Australia, New Zealand, and Pacific Islands. Edited by Harold Heatwole and Jodi Rowley. 2018. CSIRO Publishing. 248 pages, 160.00 AUS, Cloth. Also available as an E-book.

Amphibians and Reptiles of Florida. By Kenneth L. Krysko, Kevin M. Enge, and Paul E. Moler. 2019. University Press of Florida. 816 pages, 80.00 USD, Cloth.

Reptiles and Amphibians of Australia. Seventh Edition. By Harold Cogger. 2018. CSIRO Publishing. 1096 pages, 160.00 AUS, Cloth.

Field Guide to the Amphibians and Reptiles of Britain and Europe. By Jeroen Speybroeck, Wouter Beukema, Bobby Bok, and Jan Van Der Voort. Illustrated by Ilian Velikov. 2016. Bloomsbury Publishing. 432 pages, 25.00 GBP, Paper.

Field Guide to East African Reptiles. By Steve Spawls, Kim Howell, Harald Hinkel, and Michele Menegon. 2018. Bloomsbury Publishing. 624 pages, 35.00 GBP, Paper.

The Lizards, Crocodiles, and Turtles of Honduras: Systematics, Distribution, and Conservation. Bulletin of the Museum of Comparative Zoology Special Publications Series 2. By James R. McCranie. 2018. Harvard University Press. 672 pages, 44.95 USD, Paper.

ORNITHOLOGY

Snowbird: Integrative Biology and Evolutionary Diversity in the Junco. Edited by Ellen D. Ketterson and Jonathan W. Atwell. 2016. University of Chicago Press. 416 pages, 60.00 USD, Cloth, 10.00–60.00 USD, E-book.

Golden-winged Warbler Ecology, Conservation, and Habitat Management. Studies in Avian Biology Series. By Henry M. Streby, David E. Andersen, and David Buehler. 2016. CRC Press (Taylor & Francis Group) in collaboration with the American Ornithological Society. 238 pages, 152.00 USD, Cloth, 46.36 USD, E-book.

Ecology and Conservation of North American Sea Ducks. Studies in Avian Biology Series. Edited by Jean-Pierre L. Savard, Dirk V. Derksen, Dan Esler, and John M. Eadie. 2018. CRC Press (Taylor & Francis Group) in collaboration with the American Ornithological Society. 610 pages, 148.00 USD, Cloth, 55.96 USD, Paper, 55.96 USD, E-book.

Ecology and Management of Blackbirds (Icteridae) in North America. By George M. Linz, Michael L. Avery, and Richard A. Dolbeer. 2017. CRC Press (Taylor & Francis Group). 240 pages, 95.96 USD, Cloth, 43.96 USD, E-book.

Phenological Synchrony and Bird Migration: Changing Climate and Seasonal Resources in North America. Studies in Avian Biology Series. Edited by Eric M. Wood and Jherime L. Kellermann. 2017. CRC Press (Taylor & Francis Group) in collaboration with the American Ornithological Society. 246 pages, 128.00 USD, Cloth, 47.96 USD, Paper or E-book.

Birds. By Robert Bateman. Foreword by Peter Matthiessen. 2018. Firefly Books. 176 pages and 200 paintings, 29.95 CAD, Paper.

Animal Musicalities: Birds, Beasts, and Evolutionary Listening. By Rachel Mundy. 2018. Wesleyan University Press. 264 pages, 29.95 USD, Cloth, 23.99 USD, E-book.

Bird Brains: The Intelligence of Crows, Ravens, Magpies, and Jays. Revised Edition. By Candace Savage. 2018. Greystone Books. 144 pages, 29.95 CAD, Paper.

Bird Species: How They Arise, Modify and Vanish. By Dieter Thomas Tietze. 2018. Springer. 278 pages, 109.99 USD. Also available as an E-book.

Species: The Evolution of the Idea, Second Edition. By John S. Wilkins. 2018. CRC Press (Taylor & Francis Group). 389 pages, 95.96 USD, Cloth, 43.96 USD, E-book.

Swifts in a Tower. New Edition. Edited by Andrew Lack. 2018. Unicorn Publishing Group, distributed by University of Chicago Press. 260 pages, 22.95 USD, Cloth. Original edition by David Lack, published in 1956.

Urban Ornithology: 150 Years of Birds in New York City. By P.A. Buckley, Walter Sedwitz, William J. Norse, and John Kieran. 2018. Comstock Publishing Associates. 536 pages, 75.00 USD, Cloth.

Birds New to Science: Fifty Years of Avian Discoveries. By David Brewer. 2018. Christopher Helm. 416 pages, 60.00 USD, Cloth.

The Extended Specimen: Emerging Frontiers in Collections-Based Ornithological Research. Studies in Avian Biology Series. By Michael S. Webster. 2017. CRC Press (Taylor & Francis Group) in collaboration with the American Ornithological Society. 240 pages, 111.96 USD, Cloth, 43.96 USD, E-book.

Listening in the Field: Recording and the Science of Birdsong. By Joeri Bruyninckx. 2018. MIT Press. 240 pages, 34.00 USD, Cloth.

Ecology and Conservation of Birds in Urban Environments. Edited by Enrique Murgui and Marcus Hedblom. 2017. Springer. 538 pages, 219.00 USD, Cloth or Paper, 169.00 USD, E-book.

Gulls Simplified: A Comparative Approach to Identification. By Pete Dunne and Kevin T. Karlson. 2018. Princeton University Press. 208 pages, 24.95 USD, Paper. Also available as an E-book.

Landfill. By Tim Dee. 2018. Little Toller Books. 240 pages, 16.00 GBP, Cloth.

The Genius of Birds. By Jennifer Ackerman. 2017. Penguin Random House. 352 pages, 17.00 USD, Paper.

The Empire of the Eagle: An Illustrated Natural History. By Mike Unwin and David Tipling. 2018. Yale University Press. 288 pages and 400 colour illustrations, 40.00 USD, Cloth.

Belonging on an Island: Birds, Extinction, and Evolution in Hawai'i. By Daniel Lewis. 2018. Yale University Press. 320 pages, 45.00 USD, Cloth.

The House of Owls. By Tony Angell. Foreword by Robert Michael Pyle. 2016. Yale University Press. 224 pages, 18.00 USD, Paper.

Where Song Began: Australia's Birds and How They Changed the World. By Tim Low. 2016. Yale University Press. 424 pages, 32.50 USD, Cloth.

ZOOLOGY

Bats in the Anthropocene: Conservation of Bats in a Changing World. Edited by Christian C. Voigt and Tigga Kingston. 2016. Springer Open. 615 pages, 59.99 USD, Cloth. Free E-book available at <https://link.springer.com/book/10.1007%2F978-3-319-25220-9>.

And Then There Were None: The Demise of Desert Bighorn Sheep in the Pusch Ridge Wilderness. By Paul R. Krausman. Illustrated by Bethann Garramon Merkle. 2017. University of New Mexico Press. 248 pages, 65.00 USD, Cloth or E-book.

Field Guide to Carnivores of the World, 2nd Edition. By Luke Hunter. Illustrated by Priscilla Barrett. 2018. Bloomsbury Publishing. 256 pages, 25.00 GBP, Paper. Also available as an E-book.

Eager: The Surprising, Secret Life of Beavers and Why They Matter. By Ben Goldfarb. 2018. Chelsea Green Publishing. 304 pages, 24.95 USD, Cloth.

The Way of Coyote: Shared Journeys in The Urban Wilds. By Gavin Van Horn. 2018. University of Chicago Press. 224 pages, 25.00 USD, Cloth, 18.00 USD, E-book.

The Great Apes: A Short History. By Chris Herzfeld. Translated by Kevin Frey. Foreword by Jane Goodall. 2017. Yale University Press. 344 pages, 26.00 USD, Cloth.

Carnivore Minds: Who These Fearsome Animals Really Are. By G.A. Bradshaw. 2017. Yale University Press. 360 pages, 35.00 USD, Cloth.

Across the Bridge: Understanding the Origin of the Vertebrates. By Henry Gee. 2018. University of Chicago Press. 288 pages, 75.00 USD, Cloth, 25.00 USD, Paper, 10.00–25.00 USD, E-book.

Eyes to See: The Astonishing Variety of Vision in Nature. By Michael Land. 2018. Oxford University Press. 208 pages, 28.50 CAD, Cloth.

***Keepers of the Wolves. Second Edition.** By Richard P. Thiel. 2018. University of Wisconsin Press. 264 pages, 22.95 USD, Paper.

Biology and Ecology of Pike. Edited by Christian Skov and P. Anders Nilsson. 2018. CRC Press (Taylor & Francis Group). 402 pages, 151.96 USD, Cloth, 46.36 USD, E-book.

Octopus, Squid, and Cuttlefish: A Visual, Scientific Guide to the Oceans' Most Advanced Invertebrates. By Roger Hanlon, Mike Vecchione, and Louise Allcock. 2018. University of Chicago Press. 224 pages, 40.00 USD, Cloth, 24.00 USD, E-book.

***Muskellunge Management: Fifty Years of Cooperation Among Anglers, Scientists, and Fisheries Biologists.** Proceedings of the “Hugh C. Becker Memorial Muskie Symposium”, held in Minnetonka, Minnesota, 13–15 March 2016. American Fisheries Society Symposium, Volume 85. Edited by Kevin L. Kapuscinski, Timothy D. Simonson, Derek P. Crane, Steven J. Kerr, James S. Diana, and John M. Farrell. 2017. American Fisheries Society. 675 pages, 79.00 USD, Cloth or PDF.

Cutthroat Trout: Evolutionary Biology and Taxonomy. Edited by Patrick Trotter, Peter Bisson, Luke Shultz, and Brett Roper. 2018. American Fisheries Society. 362 pages, 79.00 USD, Cloth or PDF.

Sharks: Ancient Predators in a Modern Sea. Salvador Jorgensen. 2018. Firefly Books. 256 pages, 29.95 CAD, Paper.

Big Pacific: An Incredible Journey of Exploration and Revelation. Edited by Rebecca Tansley. 2017. CSIRO Publishing. 240 pages, 49.95 AUD, Cloth.

***Eye of the Shoal: A Fishwatcher's Guide to Life, the Ocean and Everything.** By Helen Scales. 2018. Bloomsbury Sigma. 288 pages, 15.29 GBP, Cloth, 8.99 GBP, Paper, 14.26 GBP, E-book.

Spineless: The Science of Jellyfish and the Art of Growing a Backbone. By Juli Berwald. 2018. Riverhead Books. 352 pages, 16.00 USD, Paper.

Squid Empire: The Rise and Fall of the Cephalopods. By Danna Staaf. 2017. ForeEdge. 256 pages, 27.95 USD, Cloth, 22.99 USD, E-book.

Orca: How We Came to Know and Love the Ocean's Greatest Predator. By Jason M. Colby. 2018. Oxford University Press. 408 pages, 29.95 CAD, Cloth. Also available as an E-book.

Spying on Whales: The Past, Present, and Future of Earth's Most Awesome Creatures. By Nick Pyenson. 2018. Viking. 336 pages, 27.00 USD, Cloth, 17.50 USD, Audiobook, 13.99 USD, E-book.

OTHER

What Species Mean: A User's Guide to the Units of Biodiversity. By Julia D. Sigwart. 2018. CRC Press (Taylor & Francis Group). 232 pages, 79.96 USD, Cloth, 43.96 USD, E-book.

Handbook of Australasian Biogeography. CRC Biogeography Series. Edited by Malte C. Ebach. 2017. CRC Press (Taylor & Francis Group). 376 pages, 84.00 USD, Cloth, 46.36 USD, E-book.

Welcome to Subirdia: Sharing Our Neighborhoods with Wrens, Robins, Woodpeckers, and Other Wildlife. By John M. Marzluff. Illustrated by Jack DeLap. 2015. Yale University Press. 320 pages, 18.00 USD, Paper.

Birders of Africa: History of a Network. By Nancy J. Jacobs. 2016. Yale University Press. 352 pages, 60.00 USD, Cloth.

Hubbard Brook: The Story of a Forest Ecosystem. By Richard T. Holmes and Gene E. Likens. 2016. Yale University Press. 288 pages and 187 colour illustrations, 45.00 USD, Cloth.

Sustaining Lake Superior: An Extraordinary Lake in a Changing World. By Nancy Langston. 2017. Yale University Press. 312 pages, 35.00 USD, Cloth.

The Human Planet: How We Created the Anthropocene. By Simon L. Lewis and Mark A. Maslin. 2018. Yale University Press. 480 pages, 25.00 USD, Cloth.

Visual Voyages: Images of Latin American Nature from Columbus to Darwin. By Daniela Bleichmar. 2017. Yale University Press in association with the Huntington Library, Art Collections, and Botanical Gardens. 240 pages, 50.00 USD, Cloth.

The Aliens Among Us: How Invasive Species Are Transforming the Planet—and Ourselves. By Leslie Anthony. 2017. Yale University Press. 400 pages, 30.00, Cloth.

Ecology and Management of Terrestrial Vertebrate Invasive Species in the United States. Edited by William C. Pitt, James C. Beasley, and Gary W. Witmer. 2017. CRC Press (Taylor & Francis Group). 403 pages, 79.95 USD, Cloth or E-book.

Conservation Criminology. Edited by Meredith L. Gore. 2017. Wiley-Blackwell. 248 pages, 103.29 CAD, Cloth, 82.99 CAD, E-book.

Biodiversity Conservation and Phylogenetic Systematics: Preserving our Evolutionary Heritage in an Extinction Crisis. Topics in Biodiversity and Conservation, Volume 14. Edited by Roseli Pellens and Philippe Grandcolas. 2016. Springer Open. 407 pages, 51.99 EU, Cloth or E-book. Open access on Springer website.

Messages from Islands: A Global Biodiversity Tour. By Ilkka Hanski. 2016. University of Chicago Press. 272 pages, 100.00 USD, Cloth, 32.50 USD, Paper, 10.00–32.50 USD, E-book.

A Year with Nature: An Almanac. By Marty Crump. 2018. University of Chicago Press. 384 pages, 30.00 USD, Cloth, 18.00 USD, E-book.

Critical Terms for Animal Studies. Edited by Lori Gruen. 2018. University of Chicago Press. 448 pages, 97.50 USD, Cloth, 32.50 USD, Paper. Also available as an E-book.;

Nature's Temples: The Complex World of Old-Growth Forests. By Joan Maloof. 2016. Timber Press. 200 pages, 27.95 USD, Cloth, 14.99 USD, E-book.

Seaweed Chronicles: A World at the Water's Edge. By Susan Hand Shetterly. 2018. Workman Publishing. 288 pages, 24.95 USD, Cloth, 11.99 USD, E-book.

Extreme Conservation: Life at the Edges of the World. By Joel Berger. 2018. University of Chicago Press. 368 pages, 22.89 USD, Cloth.

The Wizard and the Prophet: Two Remarkable Scientists and Their Dueling Visions to Shape Tomorrow's World. By Charles C. Mann. 2018. Knopf. 640 pages, 19.68 USD, Cloth, 13.55 USD, Paper.

A Wilder Time: Notes from a Geologist at the Edge of the Greenland Ice. By William E. Glassley. 2018. Bellevue Literary Press. 224 pages, 12.18 USD, Paper.

Improbable Destinies: Fate, Chance, and the Future of Evolution. By Jonathan B. Losos. 2018. Riverhead Books. 384 pages, 28.00 USD, Cloth, 17.00 USD, Paper, 12.99 USD, E-book.

A Fierce Green Fire: Aldo Leopold's Life and Legacy. New Edition. By Marybeth Lorbiecki. 2016. Oxford University Press. 400 pages, 32.95 CAD, Paper. Also available as an E-book.

Alien Species and Insect Conservation. By Tim R. New. 2016. Springer. 242 pages, 159.00 USD, Cloth, 119.00 USD, E-book.

Current Trends in Wildlife Research. Wildlife Research Monographs. Edited by Rafael Mateo, Beatriz Arroyo, and Jesus T. Garcia. 2016. Springer. 303 pages, 159.00 USD, Cloth, 119.00 USD, E-book.

Defending Biodiversity: Environmental Science and Ethics. By Jonathan A. Newman, Gary Varner, and Stefan Linquist. 2017. Cambridge University Press. 455 pages, 99.99 USD, Cloth, 47.99 USD, Paper.

Tropical Conservation: Perspectives on Local and Global Priorities. Edited by A. Alonso Aguirre and Raman Sukumar. 2017. Oxford University Press. 528 pages, 99.00 USD, Cloth.

Sacred Bovines: The Ironies of Misplaced Assumptions in Biology. By Douglas Allchin. 2017. Oxford University Press. 264 pages, 34.95 USD, Cloth. Also available as an E-book.

The New Ecology: Rethinking a Science for the Anthropocene. By Oswald J. Schmitz. 2016. Princeton University Press. 256 pages, 35.00 USD, Cloth, 22.95 USD, Paper. Also available as an E-book.

Coves of Departure: Field Notes from the Sea of Cortez. By John Seibert Farnsworth. 2018. Cornell

University Press, Comstock Publishing Associates. 168 pages, 18.95 USD, Paper.

Nature Hikes: Near-Toronto Trails and Adventures. By Janet Eagleson. Photography by Rosemary G. Hasner. 2018. Firefly Books. 240 pages, 24.95 CAD, Paper.

Rare and Wonderful: Treasures from the Oxford University Museum of Natural History. By Kate Diston and Zoë Simmons. 2018. Bodleian Library, University of Oxford. Distributed by University of Chicago Press. 224 pages and 50 colour plates, 35.00 USD, Cloth.

This Land Is Your Land: The Story of Field Biology in America. By Michael J. Lannoo. 2018. University of Chicago Press. 304 pages, 90.00 USD, Cloth, 30.00 USD, Paper, 10.00–30.00 USD, E-book.

Vernon Bailey: Writings of a Field Naturalist on the Frontier. By David J. Schmidly. 2018. Texas A&M University Press. 472 pages, 45.00 USD, Cloth. Also available as an E-book.

Land Bridges: Ancient Environments, Plant Migrations, and New World Connections. By Alan Graham. 2018. University of Chicago Press. 288 pages, 150.00 USD, Cloth, 50.00 USD, Paper, 10.00–50.00 USD, E-book.

Eastern Alpine Guide: Natural History and Conservation of Mountain Tundra East of the Rockies. Edited by Mike Jones and Liz Willey. 2018. University Press of New England. 360 pages, 35.00 USD, Paper, 34.99 USD, E-book.

The Tangled Tree: A Radical New History of Life. By David Quammen. 2018. Simon & Schuster. 480 pages, 30.00 USD, Cloth, 18.00 USD, Paper, 14.99 USD, E-book.

Unnatural Selection. By Katrina van Grouw. 2018. Princeton University Press. 304 pages and 304 black and white illustrations, 45.00 USD, Cloth.

Invasion Dynamics. By Cang Hui and David M. Richardson. 2017. Oxford University Press. 336 pages, 115.00 CAD, Cloth, 60.00 CAD, Paper. Also available as an E-book.

Conservation Drones: Mapping and Monitoring Biodiversity. By Serge A. Wich and Lian Pin Koh. 2018. Oxford University Press. 144 pages, 55.00 CAD, Cloth. Also available as an E-book.

†**The Environment: A History of the Idea.** By Paul Warde, Libby Robin, and Sverker Sörlin. 2018. Johns Hopkins University Press. 256 pages, 29.95 USD, Cloth.

News and Comment

Upcoming Meetings and Workshops

Canadian Conference on Fisheries Research

The Canadian Conference on Fisheries Research to be held 3–6 January 2019 at the London Convention Centre, London, Ontario. The theme of the conference is: ‘Resilience, Adaptation, and Mitigation Strategies for

Conserving Canada’s Aquatic Resources’. Registration is currently open. More information is available at https://www.uwo.ca/sci/ccffr_scl2019.

Society for Integrative & Comparative Biology Annual Meeting

The Society for Integrative & Comparative Biology Annual Meeting, with the American Microscopical Society, The Crustacean Society, and Animal Behavior Society, to be held 3–7 January 2019 at the Tampa

Marriott Waterside and Tampa Convention Center, Tampa, Florida. Registration is currently open. More information is available at <http://www.sicb.org/meetings/2019/index.php>.

Science, Practice & Art of Restoring Native Ecosystems Conference

The Science, Practice & Art of Restoring Native Ecosystems Conference to be held 11–12 January 2019 at the Kellogg Center, East Lansing, Michigan. Registra-

tion is currently open. More information is available at <https://conference.stewardshipnetwork.org>.

Midwest Fish & Wildlife Conference

The 79th Midwest Fish & Wildlife Conference to be held 27–30 January 2019 at the Hilton Cleveland Downtown Hotel, Cleveland, Ohio. The theme of the conference is: ‘Communicating Science to Fan the

Flames of Conservation’. Registration is currently open. More information is available at <http://www.midwestfw.org>.

Forests Ontario Annual Conference

The Forests Ontario Annual Conference to be held 8 February 2019 at the Nottawasaga Inn, Alliston, Ontario. The theme of the conference is: ‘Natural Con-

nections’. Registration is currently open. More information is available at <https://www.forestsontario.ca/community/annual-conference>.

Society for Range Management Annual Meeting

The 72nd annual meeting of the Society for Range Management to be held 10–14 February 2019 at the Hilton Minneapolis, Minneapolis, Minnesota. The

theme of the conference is: ‘Gateway to the Prairie’. Registration is currently open. More information is available at <http://annualmeeting.rangelands.org>.

Wisconsin Wetlands Association’s Wetland Science Conference

The Wetland Science Conference of the Wisconsin Wetlands Association to be held 19–21 February 2019 at the Madison Marriott West, Madison, Wisconsin. Reg-

istration is currently open. More information is available at <https://conference.wisconsinwetlands.org>.

Entomological Society of America – Southeastern Branch Meeting

The 93rd annual meeting of the Southeastern Branch of the Entomological Society of America to be held 3–6 March 2019 at the Renaissance Mobile Riverview

Plaza Hotel, Mobile, Alabama. Registration is currently open. More information is available at <https://www.entsoc.org/southeastern/2019-branch-meeting>.

Entomological Society of America – Eastern Branch Meeting

The 90th annual meeting of the Eastern Branch of the Entomological Society of America to be held 9–12 March 2019 at The Inn at Virginia Tech, Blacksburg,

Virginia. Registration is currently open. More information is available at <https://www.entsoc.org/eastern/2019-branch-meeting>.

Entomological Society of America – North Central Branch Meeting

The 74th annual meeting of the North Central Branch of the Entomological Society of America to be held 17–20 March 2019 at the Hyatt Regency Cincinnati,

Cincinnati, Ohio. Registration is currently open. More information is available at <https://www.entsoc.org/north-central/2019-branch-meeting>.

Alberta Chapter of The Wildlife Society Conference

The Alberta Chapter of The Wildlife Society Conference to be held 22–24 March 2019 at the Coast Canmore Hotel + Conference Centre, Canmore, Alberta.

The theme of the conference is: ‘Connectivity’. More information is available at <https://www.actws.ca/conference>.

Entomological Society of America – Pacific Branch Meeting

The 103rd annual meeting of the Pacific Branch of the Entomological Society of America to be held 31 March–3 April 2019 at the Hyatt Regency Mission

Bay Spa & Marina, San Diego, California. Registration is currently open. More information is available at <https://www.entsoc.org/pacific/2019-branch-meeting>.

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COVER: Common Raven (*Corvus corax*) in Kugluktuk, Nunavut, Canada. See the article in this issue by Myles Lamont, pages 254–260. This species was not one of the 10 birds newly documented as nesting near the community since 2016 and is one of the few year-round avian residents. It is commonly found in communities across the Canadian Arctic. Photo: Myles Lamont, February 2016.

Divorce in Canada Geese (*Branta canadensis*): frequency, causes, and consequences

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Abstract

Most Canada Geese (*Branta canadensis*) form lifelong pair bonds (same-mate geese), but some pairs break apart and the geese mate with new partners while their former mates are still alive (divorcees). Over 25 years, we assessed lifelong reproduction of 160 collared Canada Geese that nested for multiple years in New Haven County, Connecticut. We examined whether same-mate geese and divorcee geese differed from each other prior to or after the divorce. Fifteen percent of females and 18% of males divorced during their lifetimes. Divorces were more frequent in pairs that produced fewer hatchlings during their prior nesting year. Most divorcees that nested again did so on their former nesting territories. Replacement partners of divorcees averaged younger and had fewer years of nesting experience than the divorcees' prior mate. Usually after a divorce, one divorcee of each former pair nested immediately while the other skipped one or more years before nesting again. Under such circumstances, the partner able to nest immediately can increase its direct fitness by finding a new partner and nesting rather than foregoing the opportunity to nest that year. During their first nesting year after the divorce, the reproductive success of divorcees and same-mate geese were similar.

Key words: Canada Geese; lifelong reproduction; mate fidelity; mate selection; monogamy; pair bonds

Introduction

Many bird studies have found a positive relationship between the duration of a pair bond and the pair's reproductive success (Pyle *et al.* 2001; van de Pol *et al.* 2006). Black (2001) and Cooke *et al.* (1981) hypothesized that this was because mates were able to coordinate their behaviour so they are better able to watch for predators, defend their nesting territory from conspecifics, and provide their young with access to better foraging areas. Despite the advantages of a durable pair bond, some individuals pair with a new partner while their former partner is still alive. We refer to this as a divorce and the individuals as divorcees, terms widely used in the ornithological literature (Ens *et al.* 1993; Dhondt and Adriaensen 1994; Choudhury 1995).

Several hypotheses explain divorce in species that normally have lifelong pair bonds. Owen *et al.* (1988) hypothesized that a divorce results when a pair becomes separated during winter or migration, and one mate reached the nesting grounds before the other and pairs with a new bird before its former mate arrives (lost-mate hypothesis). The incompatible-mates hypothesis argues some geese cannot work well together when nesting due to individual incompatibilities, but these same individuals could be good partners for other geese (Coulson 1972; Choudhury 1995; Dhondt 2002). The territorial-improvement hypothesis predicts that divorces occur when one mate has the opportunity to gain

access to a better territory by switching mates (Dhondt and Adriaensen 1994; García-Navas and Sanz 2011) while the mate-improvement hypothesis argues that divorces result when one mate has an opportunity to mate with a better partner (Ens *et al.* 1993; Choudhury 1995).

Geese and swans (Anatidae) are renowned for their lifelong pair bonds; most geese and swans have only one mate during their entire lives (Bellrose 1980; Baldassarre 2014). Yet, some pairs break apart while both mates are alive and in the same area, and the former mates reproduce with others. The frequency of divorce (proportion of pairs that divorce) was <2% in Lesser Snow Geese (*Chen caerulescens caerulescens*; Cooke *et al.* 1981), <2% in Richardson's Cackling Geese (*Branta hutchinsii hutchinsii*; MacInnes and Lieff 1968), 7% in Canada Geese (*Branta canadensis*; Raveling 1988), and 8% among Barnacle Geese (*Branta leucopsis*; Black *et al.* 1996). Among swans, divorce rates were 0% in Bewick's Swans (*Cygnus bewickii*), 3.7% in Mute Swans (*Cygnus olor*), and 5.8% in Whooper Swans (*Cygnus cygnus*; Rees *et al.* 1996). Baldarrasse (2014) is the authority for the names of subspecies in this paper.

For 25 years, we studied a marked (collared) population of Canada Geese located in Connecticut to determine the frequency of divorce, why some geese divorce while others remain with their prior mates, and the consequences of divorce. We tested the hypotheses that 1) the new partners of divorcees were older and had more

years of nesting experience than their former mates (Ens *et al.* 1993; Choudhury 1995), 2) divorcees were unable to retain their prior nesting territory because a single bird cannot defend a territory alone (Abraham *et al.* 1981), 3) divorces are more common in pairs that had experienced reproduction failures (Coulson 1972), and 4) divorcees were less successful reproducing than geese that remained with their prior mates (Catry *et al.* 1997).

Methods

We examined reproduction of Canada Geese (*Branta canadensis*) in New Haven County, Connecticut, USA (centroid: 41.3267°N, 72.89043°W). The terrain is mostly flat near the coast of Long Island Sound but rises to low hills (up to 320 m) in the northern part of the county. The county has numerous ponds, streams, and rivers. Several reservoirs have been created to provide power or store water.

Canada Geese started nesting in New Haven County during the late 1970s (Conover and Chasko 1985). These geese were non-migratory and rarely left the county once they started nesting (Conover 2012). We started banding these geese and studying their movements, survival, and reproductive success in 1984 and continued through 2008.

Most Canada Geese in the county built their nests on islands, abandoned Muskrat (*Ondatra zibethicus*) lodges, and abandoned Mute Swan nests scattered throughout the county but brought their broods to one of three brood-rearing sites, sometimes travelling several kilometres to reach them (Conover 2012). Each brood-rearing site was located on a reservoir complex of two to four lakes. The three complexes were Konold's Pond-Lake Dawson, Whitney Lakes, and Maltby Lakes. Adjacent to these lakes were golf courses, shopping centres, and apartment buildings. The broods usually foraged on the lawns associated with these areas (Conover and Kania 1991). For instance, the broods from Maltby Lake complex spent most of their time on Yale University Golf Course, which offered both rich foraging grounds (lawns) and sanctuaries (water hazards and ponds; Conover 2012).

In Connecticut, Canada Goose eggs hatch in late April and early May, and goslings fledge in early July (Conover and Frank 2018). Adult geese moult their primary feathers and become flightless in late June. During the moult, we rounded up goslings and adults at all brood-rearing areas in New Haven County by herding them into funnel traps (Smith *et al.* 1999). We weighed each bird upon capture, determined its sex through a cloacal examination, and banded it with a U.S. Geological Survey (USGS) aluminum leg band and either a large leg band or neck collar made of plastic by Spinner Plastics (Springfield, Illinois, USA). Each large leg band and neck collar had a unique combination of letters and numbers large enough (letters were 1.3 cm in height on leg bands and 3 cm on collars) so we could

identify individuals from far enough away that our presence did not disturb the geese. Collars were identical to those used extensively throughout the Atlantic Flyway (Hestbeck and Malecki 1989). We replaced worn or lost leg bands or neck collars by identifying individuals by their USGS leg bands. We searched Connecticut for geese wearing large leg bands and neck collars year-round and observed most birds dozens of times each year. We also used sightings of marked geese reported to the U.S. Bird Banding Lab to locate birds. Once Canada Geese started nesting, they exhibited great fidelity to nesting and brood-rearing areas; only one goose we observed nesting in New Haven County was ever observed nesting outside the area (Conover 2012). We considered a female to have reproduced during any year that it was observed incubating a nest or attending a brood and a male to have reproduced during any year that it was observed attending a brood or defending a territory in which a female was incubating a nest.

All geese were banded by us when they were goslings (HY geese) or adults (AHY geese) prior to 2001; those born after 2001 were excluded from the analysis because we were interested in the long-term consequences of divorce. We knew the age of all HY geese, but not for AHY geese. Because most Canada Geese breeding in the area were banded as goslings, most birds first captured as adults were probably relatively young (i.e., one to three years old). Hence, we assumed each AHY goose was two years old when first banded. Including AHY geese in our study introduced some imprecision into the aging of geese. Previously, Conover (2012) assessed whether any bias was created by including AHY geese in the database and found HY and AHY geese were similar in all measures of age-related reproduction.

We visited every known Canada Goose nest in New Haven County to determine clutch size. Goose nests were located by flights over the county by Connecticut Department of Environmental Protection staff and by searching all water bodies appearing on USGS topographical maps from shore or a boat. Most nests were discovered by observing a lone male. We observed each nest from a distance at least weekly to determine if it was still being incubated. We mapped nesting territories each year by noting the location of both mates during the incubation period and where they confronted intruding geese. Usually the territory consisted of a small island or shoreline and the water around it. Sometimes, we recorded the exact location of nesting territories, but not always.

We determined brood sizes at least twice a week for the first month after hatching and then every week or two until the goslings could fly in July. Broods were identified by the parents that were attending them. Individual goslings were not marked at hatching, but broods were individually dyed or marked with ink at hatching when multiple broods were at the same place so we could keep track of goslings. We assumed all gos-

lings in a brood died when the parents were observed without their brood, provided that 1) none of their marked goslings were observed with another brood and 2) no other brood at the same site increased in size when the brood disappeared.

We recorded brood sizes at hatching and fledgling. We defined brood size at hatching as the number of goslings in a brood when first sighted (usually within 48 hours of hatching), and brood size at fledging as the number of goslings in a brood the day before we captured the parents and brood, which took place immediately before the goslings gained the ability to fly. We recorded whether the parents raised their brood by themselves (two-parent family) or whether they joined with other parents to form a gang brood. A gang brood occurred when two or more families joined together with their offspring, resulting in a cohesive group of young accompanied by four or more parents (Conover 2009). The number of fledglings in a gang brood was divided by the number of adult pairs attending the brood to determine the number of fledglings each pair produced, with the provision that the number of fledglings assigned to a pair could not exceed its brood size at hatching.

We identified nesting adults by their band or collar numbers and determined their age, the age and identity of their mates, clutch size, brood size at hatching, and brood size at fledging. We noted if the marked geese had nested on the same territory during prior years.

Usually, paired geese nested together year after year, but sometimes, we found a banded goose nesting with a new partner while its former partner was still alive and in the area. We defined this as a divorce. At least one of the prior partners had to nest again because otherwise we would not know a divorce had occurred. We wanted to compare divorcees to other geese that remained paired with their former mates (same-mate geese). There were two criteria for a nesting goose to be a subject for this study (i.e., either a divorcee or same-mate geese). First, both the subject and its mate had to wear either a large leg band or neck collar so that we could individually recognize them. Second, a subject had to nest at least two years during its life so that it had the opportunity to switch mates from one year to the next and its former mate had to be alive and in the area during the second year the subject nested. All geese that met these criteria in New Haven County were included in this study.

We determined the divorce rate, which is the proportion of subjects that became a divorcee anytime during their lives, and the annual divorce rate, which is the proportion of nesting birds that initiated a divorce from one year to the next. The annual divorce rate was calculated as the number of divorcees divided by the total number of nest-years by subjects after their first nesting year. Each subject's first nesting year was excluded from this analysis because a divorce cannot occur during the first nesting year. We compared the frequency of divorce among females and males using a 2×2 contingency test

corrected for continuity (Siegel 1956). Results were considered statistically significant when $P \leq 0.05$. We hypothesized that some divorces result when a goose that has nested during a prior year has an opportunity to move to a better nesting territory by divorcing its former mate and mating with a new partner that had a better territory. To test this hypothesis, we determined the number of divorcees that remained on the same territory they had prior to the divorce.

In Canada Geese, reproductive performance is positively correlated with parental age and nesting experience (Baldassarre 2014), and we hypothesized that divorces result when one mate has the opportunity to nest with an older, more experienced goose than its current mate. We used a paired t -test (Siegel 1956) to compare the age and years of nesting experience of a divorcee's replacement mate (i.e., the individual a divorcee nested with after its divorce) during its first nesting year with the divorcee against the age and prior nesting experience of divorcee's prior mate (i.e., the individual a divorcee nested with prior to its divorce) during that same year.

Divorce prediction analyses

Factors predicting the probability of divorce were evaluated with binary generalized linear models (GLM). Same-mate geese were coded as the reference category. Models with all possible combinations of age, sex, mass, and reproductive success prior to divorce were compared using Akaike Information Criterion adjusted for small sample sizes (AICc) and Akaike weights (w_i). Metrics of reproductive success were highly correlated; thus, we selected the best metric for reproductive success by comparing single-variable models with AICc. Only the reproductive success variable with the lowest AICc was used in models with age, sex, and body mass to predict divorce. We used these models to test the hypotheses that divorces were more frequent among pairs that had been less successful during their last nesting attempt or during all nesting attempts in the past or when one of the partners was in poor body condition.

Divorce consequence analyses

We used binary GLMs to compare divorcees to same-mate geese to determine the reproductive benefits or costs of a divorce. Same-mate geese were coded as the reference category. For this analysis, we compared reproductive success of divorcees to same-mate geese after divorce. We also used variables describing the change in these reproductive success variables from before divorce to after divorce; these variables describing change were calculated as reproductive success after divorce minus reproductive success prior to divorce (e.g., brood size during the year after the divorce minus brood size the year prior to divorce). Models with all possible combinations of age, sex, reproductive success after divorce, and change in reproductive success were compared with AICc and w_i . To avoid auto-correlation of reproductive success metrics, we selected the best metric for reproductive success after a divorce (brood size at hatching,

or brood size at fledging the year after a divorce or the number of fledglings produced during all nesting years following a divorce) by comparing single variable models with AICc. The same procedure was conducted to select the best predictor of change in reproductive success. We used the best post-divorce reproductive variable and the best change in reproductive success variable based on AICc to compare the reproductive consequences of divorce.

All GLMs were evaluated using statistical program R (R Core Development Team 2015). For divorce prediction and divorce consequence analyses, we report on variables that were informative (85% CI of parameter estimates that did not overlap 0) and variables that were highly precise (95% CI of parameter estimates that did not overlap 0). For the divorce consequence analysis, we compared the nesting year following a divorce for divorcees with the nesting year following the randomly selected year for same-mate geese. Likewise, we compared for divorcees all nesting years following a divorce with all nesting years following the selected nesting year for same-mate geese.

Results

We banded 858 females of which 207 nested at least once, and 883 males of which 152 nested at least once. We observed 84 females and 76 males that nested for multiple years; these were the subjects of this study. Among them, 13 females (15%) and 14 males (18%) divorced; the divorce frequency did not differ between sexes ($\chi^2_1 = 0.25$, $P = 0.62$). The annual divorce rate was 7.6% for females based on 172 nest-years and 7.3% for males based on 190 nest-years (first nesting years were not included because birds cannot divorce during their first nesting year). Annual divorce rates were similar among female and male subjects ($\chi^2_1 = 0.01$, $P = 0.95$). No divorcee ever returned to its original partner following a divorce.

Prior mates of female divorcees were older ($t_{10} = 2.21$, $P = 0.05$) and had more years of nesting experience ($t_{10} = 4.66$, $P = 0.001$) than the replacement mates of female divorcees; prior mates were 7.8 ± 3.9 (mean \pm SD) years old and had 3.3 ± 3.6 years of experience while the replacement mates were 5.0 ± 3.2 years old and had 1.1 ± 1.0 years of experience. Male divorcees' prior mates also were older ($t_{11} = 2.76$, $P = 0.02$) and had more years of nesting experience ($t_{11} = 2.86$, $P = 0.02$) than the replacements; prior mates were 7.8 ± 3.9 years old and had 3.3 ± 3.6 years of experience while replacement mates were 5.0 years old and had 1.1 ± 1.0 years of nesting experience.

We often did not record the exact location of nesting territories, but for four male and four female divorcees we noted the nesting territories before and after their divorce. All of the males retained their former nesting territories after their divorces, as did three females. For the one female exception, its former partner retained its former nesting territory, and the female divorcee moved

to a new nesting territory on an island in an adjacent lake.

Divorce prediction analyses

Our GLMs indicated body mass prior to divorce was a poor predictor of the probability of divorcing. Thus, body mass was excluded from AIC modeling. We used the brood size at hatching in our GLM modelling because it was the best reproductive metric for predicting divorce.

Our best GLM for predicting divorce had $w_i = 0.28$ and indicated pairs with small broods at hatching were more likely to divorce in the subsequent year (Table 1). Future divorcees produced fewer hatchlings prior to divorce than same-mate pairs (parameter estimate = -0.18 [95% CI = -0.38 – 0.00]). However, the best GLM model was only 1.67 AICc lower than the intercept-only model indicating while the effect of brood size at hatching was a precise predictor (based on 95% CI) of the probability of divorce, the model did not account for much of the variance in the data. Although two models that included age prior to divorce ($\Delta\text{AICc} = 0.92$, $w_i = 0.18$ and $\Delta\text{AICc} = 1.5$, $w_i = 0.13$) had w_i similar to our top AICc model, age had parameter estimates with 85% CI that widely overlapped zero in both models. No model with sex was better than the intercept-only model (Table 1). This indicated age prior to divorce and sex was not different among same-mate geese and geese that divorced.

Divorce consequences analyses

We compared the reproductive success of 23 divorcees (13 females and 10 males) to 110 same-mate geese (58 females and 52 males) during their first nesting year after the divorce. We used brood size at hatching during the year following divorce, the difference in number of fledglings in the final nesting year before divorce, and number of fledglings in the next nesting year after divorce in AIC modelling to compare geese that divorced to geese that nested a second year with their former mate. Although multiple models that also included age post-divorce, sex, and/or change in fledglings per nesting years were within $\Delta\text{AICc} = 4$ and cumulative $w_i = 0.95$ (Table 2), all of these variables had parameter estimates with 85% CI that overlapped zero in both models. Thus, we decided to only discuss the top model as the most parsimonious description of the consequences of divorce. Our best GLM for assessing the consequences of divorce had $w_i = 0.22$ and indicated divorcees had smaller brood sizes at hatching and more years of nesting hiatus compared to same-mate geese (Figure 1). The poor fit of any change in reproductive success variable indicated neither divorcees nor same-mate geese had increased reproductive success with successive nesting years.

Discussion

Canada Geese are long-lived. In New Haven County, Connecticut, 15% of nesting geese that were recruited

TABLE 1. Results of generalized linear models comparing Canada Geese (*Branta canadensis*) that will divorce their mates during their next nesting year (13 females and 14 males) to geese that will remain paired with their prior mate during their next nesting year (58 females and 52 males). Models were used to determine why some geese divorce but not others. Models were compared with Akaike Information Criterion adjusted for small sample sizes (AICc) and Akaike weights (w_i). Data were from the divorcees' last year with their prior mate compared to the same-mates' first of two years nesting with the same mate. Dependent variables included the subjects' age, sex, and brood size at hatching. Data were collected in New Haven County, Connecticut (1984–2008).

Models	K	ΔAICc	w_i	Deviance
Brood size at hatch*	2	0.00	0.28	132.26
Brood size at hatch + age	3	0.92	0.18	131.10
Age	2	1.50	0.13	133.76
Intercept only	1	1.67	0.12	135.99
Brood size at hatch + sex	3	1.96	0.11	132.13
Brood size at hatch + age + sex	4	2.81	0.07	130.86
Age + sex	3	3.22	0.06	133.39
Sex	2	3.55	0.05	135.81

*AICc = 136.40.

Table 2. Top 10 generalized linear models comparing divorced Canada Geese (*Branta canadensis*; 13 females and 14 males) to geese that will remained paired with their same mate (58 females and 52 males). These models were used to determine if divorce reduces the ability of geese to reproduce. Models were compared with Akaike Information Criterion adjusted for small sample sizes (AICc) and Akaike weights (w_i). Data were from the first nesting year or all years after divorce for divorcees compared to the same-mates' second year nesting or all subsequent years with the same mate. Dependent variables included the subjects' age, sex, brood size at hatching, and change in fledglings produced per year (ΔFPY). Data were collected in New Haven County, Connecticut (1984–2008).

Models	K	ΔAICc	w_i	Deviance
Brood size at hatch + nesting hiatus*	3	0.00	0.22	120.92
Brood size at hatch + nesting hiatus + age	4	0.75	0.15	119.55
Brood size at hatch + ΔFPY + nesting hiatus	4	1.59	0.10	120.39
Brood size at hatch + nesting hiatus + sex	4	1.83	0.09	120.63
Brood size at hatch + ΔFPY + nesting hiatus + age	5	2.40	0.07	119.04
Brood size at hatch + nesting hiatus + age + sex	5	2.45	0.06	119.09
Nesting hiatus + age	3	3.18	0.04	124.10
Nesting hiatus	2	3.32	0.04	126.33
Brood size at hatch + ΔFPY + nesting hiatus + sex	5	3.50	0.04	120.14
ΔFPY + nesting hiatus	3	4.04	0.03	124.96

*AICc = 127.10.

Intercept only AICc = 138.00.

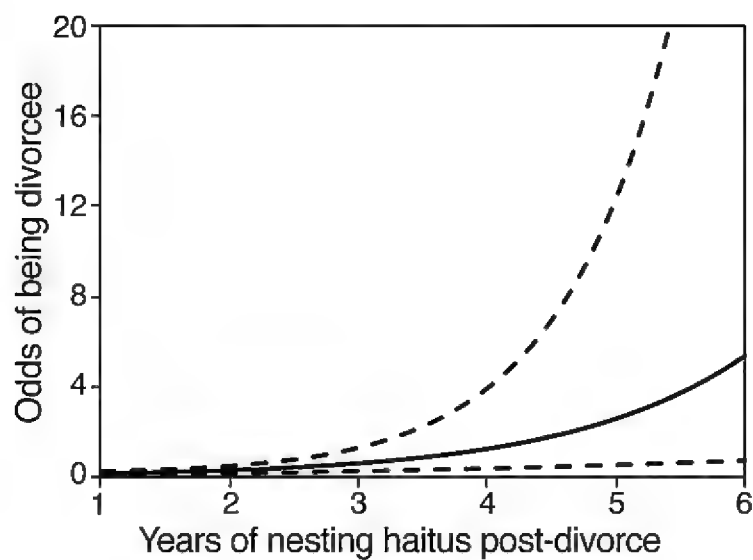


FIGURE 1. Predicted odds of Canada Geese (*Branta canadensis*) being a divorcee (solid lines) compared to a same-mate pair with 95% CI (broken lines) from generalized linear models comparing post-divorce or second year reproductive measures (divorcees to same-mate pairs, respectively).

into the breeding population lived more than 15 years, and 3% lived more than 20 years (Conover 2013). Despite their longevity, most Canada Geese nest with only one mate during their lives; 15% of females and 18% of males divorced during their lives. Raveling (1988) reported a 7% divorce rate among Canada Geese nesting in Manitoba, Canada.

Several hypotheses have been proposed to explain why divorces occur (Table 3). Owen *et al.* (1988) reported most divorces in Barnacle Geese resulted from pairs that became separated during migration or on the wintering grounds and were unable to find each other (the lost-mate hypothesis). This hypothesis, also called the asynchronous-arrival hypothesis for species where mates remain apart during the winter and reunite on the breeding grounds, does not explain divorce among our subjects. In New Haven County, Canada Geese are year-round residents; any pairs that became separated could easily relocate each other. During fall and winter, geese roost in large groups on large waterbodies (e.g.,

TABLE 3. Hypotheses to explain divorce in monogamous birds.

Hypothesis	Reference	Explanation	Supported by our study?
Lost mate	Owen <i>et al.</i> 1988; Ludwig and Becker 2006	Divorce occurs when mates become separated.	No. Our geese were non-migratory and mates could find each other if separated. Nevertheless, divorces still occurred.
Incompatible mates	Coulson 1972	Some birds cannot work together as pairs due to personal differences.	No. Divorces occurred after years of successful nesting. Nest success did not increase after divorce.
Territorial improvement	Dhondt and Adriaenssen 1994	One mate divorces to obtain a better territory.	No. Few divorcees changed territories.
Mate improvement	Ens <i>et al.</i> 1993; Choudhury 1995	One mate divorces to obtain a higher-quality mate.	No. Quality of new mates were similar to former mates. Nesting success did not increase after a divorce.
Unwilling partner	Our study	Divorces occur during a year when one goose is willing to nest but its partner is not.	Yes. One former mate in each pair failed to nest the year after a divorce.

New Haven Harbor, Konolds Pond, and Whitney Lake in our study area). Usually, individual geese use the same roost every night unless disturbed (M.C. pers. obs.). Hence, any goose pair that became separated during the day could reestablish contact that same night.

The incompatible-mates hypothesis argues some birds cannot work well together when nesting due to individual incompatibilities, but these same individuals could be good partners for other birds (Coulson 1972; Choudhury 1995; Dhondt 2002). If this hypothesis is correct, then divorces should be more frequent among young birds than old birds, and divorces should occur soon after a pair starts nesting. This hypothesis also predicts both partners should re-nest quickly following a divorce, and the reproductive success of both partners should increase after divorce. Our results do not support this hypothesis because nesting success of divorcees was similar before and after the divorce. Divorcees were not younger than same-mate geese, and divorce often occurred after pairs had nested together for several years. In contrast to our findings, Raveling (1988) reported that the four divorces he observed in Canada Geese all occurred after only one or two nesting seasons with their former partners.

The territorial-improvement hypothesis predicted that divorces occur when one mate (the initiator) switched to a new mate to gain access to a better territory (Dhondt and Adriaenssen 1994; García-Navas and Sanz 2011). In Eurasian Magpies (*Pica pica*) and European Nuthatches (*Sitta europaea*), divorce resulted when a neighbouring bird with a higher-quality territory disappeared. In this situation, a male with a lower-quality territory abandoned its partner to pair with the widow and take over the higher-quality territory (Baeyens 1981; Matthysen 1990). Also supporting this hypothesis were the findings of Heg *et al.* (2003) that European Oystercatchers (*Haematopus ostralegus*) with low-quality nesting territories were more likely to divorce than birds with high-quality territories. We located the nesting territo-

ry for eight divorcees both before and after the divorce; all but one occupied the same territories both before and after the divorce. Hence, our results do not indicate Canada Geese divorce to obtain a better territory.

The mate-improvement hypothesis predicted divorcees resulted when one mate tries to increase its reproductive success by switching to a higher-quality mate (Table 3). However, we found that the previous mates of divorcees were both older and had more years of nesting experience than did their replacements. Furthermore, this hypothesis predicted the reproductive success of divorcees should increase after a divorce (Ens *et al.* 1993). However, we found divorces did not improve reproductive success. In Barnacle Geese, divorcees produced fewer young with their new mates than they had during their last year with their former spouse, but this was only true for their first year of nesting with their new mate (Owen *et al.* 1988; Forslund and Larsson 1991).

Out of 23 divorced pairs, we found one member of each divorced pair failed to nest during the year of the divorce with only one exception. This suggests at least some divorces occur when one mate is willing and able to nest, but its partner is not. We propose this as a new hypothesis to explain divorce in Canada Geese: the unwilling-mate hypothesis. That is, divorces occur during a year when one mate wants to reproduce, and its partner does not. Under such circumstances, the willing partner can increase its direct fitness by finding another mate and reproducing rather than foregoing the opportunity to nest that year. Unfortunately, other studies did not report if both members of a divorced pair nested during the first year following the divorce.

We found divorcees were more likely to take a nesting hiatus than same-mate geese. During the first nesting year following divorce, divorcees were older than same-mate geese and produced smaller broods at hatching. In Lesser Snow Geese, divorcees and same-mate individuals were similar in their reproductive success (Cooke *et al.* 1981); the same was true in Barnacle Geese after

their first year following the divorce (Black *et al.* 1996). In contrast, Great Skua (*Stercorarius skua*) divorcees fared worse than same-mate birds in annual reproduction (Catry *et al.* 1997).

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Early and late births in high-latitude populations of free-ranging Bison (*Bison bison*)

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Abstract

The timing of parturition in high-latitude populations of Bison (*Bison bison*) is not well documented, but previous observations have indicated that births do not start until mid-May and largely end in late June or early July, similar to those of other northern ungulates. In three high-latitude Bison populations in northwestern Canada, the onset of parturition occurred as early as late March and early April—5–6 weeks earlier than previously observed—and two isolated cases of late births occurred in mid-November and mid-December. Our observations suggest that the onset of parturition in high-latitude Bison can be earlier than previously known, and late births, while apparently rare, may occur. Determining whether our observations signal a substantial, lasting shift in the timing and, possibly, synchrony of parturition in high-latitude populations of Bison will require further monitoring for early-born calves.

Key words: Bison; *Bison bison*; calving; phenology; parturition

Introduction

The birthing season for ungulates living at high latitudes is short. In northern North America, parturition by most ungulates occurs within four weeks, beginning in mid-May, peaking in late May, and tapering off by mid-June (e.g., Adams and Dale 1998; Bowyer *et al.* 1998). Where the environment is distinctly seasonal, there is strong selection toward synchrony in births—both within and between species—likely in response to a short plant-growing season and, perhaps secondarily, predation pressure. Parturition outside this “birth pulse” is of interest (e.g., Rosatte and Neuhold 2006; Jacques *et al.* 2007) because it aids in better understanding plasticity in the timing of births (Keller *et al.* 2015), and it may be maladaptive if survival or fitness is compromised for early- or late-born animals (Estes 1976; Festa-Bianchet 1988).

Bison (*Bison bison*) are an apparent exception among northern ungulates in that parturition is thought to be asynchronous compared with that of sympatric ungulates (Rutberg 1984; Green and Rothstein 1993a); however, most data on the timing of parturition of Bison are from populations at lower latitudes ($\leq 49^\circ\text{N}$). During a five-year study (1985–1989) in Badlands National Park, South Dakota, Berger and Cunningham (1994) recorded the onset of parturition by Plains Bison (*B. b. bison*) between 3 and 7 April, with a median birth date of 2–8 May. In Wind Cave National Park, South Dakota, Green and Rothstein (1993b) reported the first births of Bison on 4–7 April, peaking in late April or early May; although varying among years ($n = 3$; 1982–1984), the mean length of the birth season—defined as period over which 80% of births occurred—was 53.7 ± 10.2

(SE) days. In Yellowstone National Park, Wyoming, predicted parturition has varied widely among years and herds, with the onset occurring from 31 March to 12 April and 10–27 April for the Northern and Central herds, respectively (Gogan *et al.* 2005; Jones *et al.* 2010). The median date of parturition for these herds differed by 16 days (6 May and 22 May, respectively), indicating variation in the timing of births even among closely adjacent populations. In all of the above populations of Plains Bison, the length of the birthing season varied annually, but largely began in early April and concluded by mid- to late June. A few calves were born abnormally late, including into September for most studied populations of Plains Bison, and, in exceptional cases, into November in Wind Cave (Green and Rothstein 1993a) and Yellowstone (B. Pratt-Bergstrom pers. comm. January 2012) national parks.

Unfortunately, similar field data are not available for parturition dates of free-ranging Wood Bison (*B. b. athabasca*), which occur at high latitudes ($>56^\circ\text{N}$), where seasonal constraints are more pronounced. Geographic variation in the timing of Bison parturition has been postulated, with the onset of parturition and median birth date later and synchronicity of births greater in northern than in southern populations (Berger and Cunningham 1994; Gogan *et al.* 2005). For mountain sheep (*Ovis* spp.), Bunnell (1982) observed a strong relation between latitude and the onset of parturition, with later dates of first births in more northern populations. Correspondingly, for Wood Bison, the onset of parturition in Wood Buffalo National Park, Alberta and Northwest Territories, was reported as 10 May (Soper 1941) and 12 May (Carbyn and Trottier 1987), notably, more

than a month later than observed for Plains Bison in the contiguous USA.

Anecdotal observations from our field surveys in northwestern Canada over the past ≥ 16 years concur that parturition by Wood Bison largely occurs at about the same time as that for sympatric ungulates, e.g., Caribou (*Rangifer tarandus*), Moose (*Alces americanus*), although it may start earlier, i.e., early May, and end later, i.e., late June, suggesting that the timing of forage availability, i.e., spring green-up, also strongly influences the timing of calving by Bison at high latitudes. Births outside this period have not been observed. Here, we document recent observations of unusually early- or late-born Bison calves from three reintroduced populations in northwestern Canada.

Observations

Our observations were from the Aishihik population in southwestern Yukon, Canada (Jung 2015; Jung *et al.* 2015), and the Nahanni and Nordquist populations, which occur at the nexus of the Northwest Territories, Yukon, and British Columbia, Canada (Jung 2017; Jung and Larter 2017), all located between 59°N and 61°N.

These populations were monitored irregularly by wildlife management agency personnel during the parturition period. We used the description of coat colour changes in Bison calves provided by Olson (2005) to crudely estimate the parturition date of those born late.

Early-born calves

On 4 April 2013, we observed a calf from the Nahanni population, which was assumed born the previous day. In 2015 and 2016, we observed Bison calves from the Aishihik population, presumably born in early April (Table 1), with the earliest calf seen on 4 April 2016. Further, in the first week of April 2016 and 2017, lactating females that had recently been suckled were observed in the Aishihik population (Table 1). Based on a physical examination of the uterine tract of two lactating Bison shot during 4–6 April 2016, these females may have recently given birth. For a lactating female shot on 5 April 2017, the predicted birth date was possibly mid-March, based on measurements of the uterus. We note, however, that lactation itself is not unequivocal evidence that the female recently gave birth, as she may have been suckling her calf from the previous year.

TABLE 1. Observations of early- and late-born Bison (*Bison bison*) calves in northwestern Canada.

Observation date(s)	Observation	Population
<i>Early-born calves</i>		
4 April 2013	Newborn calf near Fort Liard, Northwest Territories. Birth occurred immediately after a late-season snow storm (F. Bertrand pers. comm. April 2013). Date of parturition assumed to be 3 April.	Nahanni
27–29 April 2015	Several dozen small, reddish calves in mixed cow–calf groups during aerial surveys near Haines Junction, Yukon (R. Drummond and R. Osborne pers. comm. April 2015). Date of parturition unknown, but assumed to be early or mid-April.	Aishihik
4–6 April 2016	Several newborn calves during aerial surveys for Bison near Haines Junction, Yukon (R. Drummond and R. Osborne pers. comm. April 2016). On 4 April 2016, we observed two harvested adult female Bison from the same area that were lactating. The onset of parturition is assumed to be earlier than 4 April.	Aishihik
4–6 April 2017	Aerial surveys for Bison in the same area as in 2015 and 2016 near Haines Junction, Yukon, did not show any calves. However, on 4 and 5 April 2017, we observed two harvested adult female Bison from the same area that were lactating. Based on a physical examination of the uterine tract, onset of parturition was estimated to be 28 March for one bison (M. Vanderkop pers. comm. April 2017).	Aishihik
<i>Late-born calves</i>		
17 March 2005	Reddish-brown calf in a group of 11 Bison near Haines Junction, Yukon (D. Drummond pers. comm. March 2005), noticeably smaller than other calves in the area. Based on Olson (2005), we estimated that the calf was probably 10–13 weeks old when observed and, thus, likely born in mid-December.	Aishihik
7 January 2012	Small calf with a reddish coat in a group of 26 Bison near Liard River, British Columbia, about 30–40% the size of seven other calves in the group. Based on descriptions of size and colouration and photographs provided by Olson (2005), we estimate that the calf was probably 8–10 weeks old when observed and, thus, was born in early to mid-November.	Nordquist

Late-born calves

Bison born late were rarely recorded; however, we documented two instances from two populations in northwestern Canada (Table 1). These calves were substantially smaller than other calves observed, and pelage colour also differed. Based on descriptions of size and colouration and photographs provided by Olson (2005), we estimate that these calves were born in mid-December and early to mid-November (Table 1).

Discussion

Our observations provide evidence of parturition in early April, and possibly as early as late March, in at least two high-latitude populations of Wood Bison—5–6 weeks earlier than that reported from Wood Buffalo National Park (Soper 1941; Carbyn and Trottier 1987) and earlier observations for the Aishihik and Nahanni populations by wildlife management agency biologists and conservation officers.

It is uncertain whether the earlier onset of parturition that we observed has occurred previously and gone unnoticed or if there has been a shift in the date of first births in recent years. We believe that the latter is more plausible, given that observations of Bison in late March and April by wildlife management agency personnel, Bison hunters, and local residents have not included any reports of calves born earlier than May before 2013. Detailed studies of the timing of parturition in Plains Bison in more southern latitudes (Green and Rothstein 1993a; Berger and Cunningham 1994; Gogan *et al.* 2005) and other ungulates, e.g., Thinhorn Sheep (*Ovis dalli*; Rachlow and Bowyer 1991) provide evidence of annual variation that may exceed 2–3 weeks. Moreover, the onset of parturition in Bison at Yellowstone National Park has shifted from late March to mid-April over 55 years from 1941 to 1997 (Gogan *et al.* 2005; Jones *et al.* 2010), demonstrating that changes in the timing of parturition for Bison can occur over longer time scales. Whether the early births we observed indicates a shift in the timing of parturition in Bison from the Aishihik population is unknown; showing this would require further monitoring for early-born calves.

Although the onset of parturition in southern populations of Plains Bison normally occurs around early April to match the phenology of food availability (see Introduction), early births in the Aishihik and Nahanni populations have occurred while temperatures were below freezing at night and patches of snow persisted on the ground, indicating a mismatch between early births and spring green-up of forage resources. Generally, calves born earlier in the season may have an advantage over their cohorts that may last their lifetimes (Festa-Bianchet 1988), but those born early in suboptimal conditions, possibly because their mothers were in poor body condition, may not have an advantage (Berger and Cunningham 1994). In the latter case, the prognosis for their survival is poor.

Similarly, the fate of late-born Bison is unknown. However, the late-born calves observed had both survived the critical neonatal period (i.e., the first month after being born) during early winter at high latitudes, indicating that they may survive the rest of the winter. In other instances of late-born calves, it has been assumed that the mother was in poor physical condition during the peak of conception and bred later in the season when her body stores had increased. However, the fate of these early- and late-born Bison is unknown.

In conclusion, our observations are of scientific interest because they provide new information on apparently extreme birth dates for high-latitude Bison, and they demonstrate some flexibility in the onset of parturition in these populations. It appears that parturition at high latitudes may begin in late March and, in exceptional cases, extend into December. Overall, however, the timing of parturition for Bison appears to be largely synchronous with spring green-up, albeit with a wider range of dates than for other ungulates in the region.

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Habitat selection by Common Gartersnakes (*Thamnophis sirtalis*) is affected by vegetation structure but not by location of Northern Leopard Frog (*Lithobates pipiens*) prey

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Abstract

Understanding the factors affecting habitat selection of species is important for effective management and for conservation because habitat selection affects fitness. We tested the competing, but not mutually exclusive, hypotheses that habitat selection of Common Gartersnakes (*Thamnophis sirtalis*) at a fine spatial scale is driven by vegetation structure or by Northern Leopard Frog (*Lithobates pipiens*) prey abundance. We conducted surveys for snakes and frogs in six, 1-ha study grids in eastern Ontario in 2014 and 2015. Common Gartersnakes used areas dominated by forbs more than expected based on availability, and used grassy areas less than expected based on availability. Gartersnakes showed no preference for sites with more frogs. Thus, vegetation structure is important in habitat selection of Common Gartersnakes, but Northern Leopard Frog abundance is not. Common Gartersnakes and Northern Leopard Frogs did have a preference for forbs, but gartersnakes do not appear to be using habitat specifically based on frog abundance at a fine scale. Future work should study habitat use by snakes over a longer period to account for high variability in frog abundance and for temporal changes in habitat structure. Future work should also examine the distribution of other prey items in relation to the distribution of snakes.

Key words: Common Gartersnake; *Thamnophis sirtalis*; Northern Leopard Frog; *Lithobates pipiens*; eastern Ontario; habitat selection; habitat structure; prey; predator; wetland

Introduction

Habitat selection by animals is important because it affects their fitness (Fretwell and Lucas 1969; Rosenzweig 1981; Morris 1988, 2003a). Individuals should make adaptive habitat selection decisions to maximize their fitness (Morris 2011). Identifying which resources are most important to a species can be a crucial step in not only understanding habitat selection and fitness, but also in the management and conservation of a species (Morris 2003a,b, 2011). Habitat selection can be defined as “the process whereby individuals preferentially use, or occupy, a non-random set of available habitats” (Morris 2003a: 2). In this study, we examined habitat selection by snakes in relation to vegetation characteristics, water levels, and amphibian abundance in wetlands near Ottawa, Ontario, Canada. The only snake species that we encountered in sufficient numbers for statistical analyses was Common Gartersnake (*Thamnophis sirtalis*), therefore our study focusses on this species.

Although *T. sirtalis* have been studied for decades, few studies have explicitly examined their habitat preferences. Nevertheless, some of the variation across their range has been described by Ernst and Ernst (2003). Carpenter (1952) found that over 70% of *T. sirtalis* encountered were in grassy habitats, with most of the re-

mainder associated with wetlands. Fitch (1965) found that *T. sirtalis* preferred relatively open habitats, including pond margins, meadows, fields, and edges of woodlands. Hart (1979) found *T. sirtalis* more in marsh habitat than pond habitat, and typically in areas with low moisture content. Charland and Gregory (1995) found that *T. sirtalis* showed a strong preference for areas with more overhead cover, and avoided open water, but also found that gravid females preferred warmer, rocky habitats. Burger *et al.* (2004) found that *T. sirtalis* in a riparian habitat showed a preference for basking in open areas on the ground rather than on branches or logs. Gregory (1984) found that *T. sirtalis* in coastal British Columbia were only found at sites that were dominated by freshwater rather than saltwater. Our work with *T. sirtalis* in eastern Ontario and western Quebec (Halliday and Blouin-Demers 2015, 2016, 2017; Halliday *et al.* 2015) demonstrated a density-independent preference for field over forest habitat, likely because fields have more optimal temperatures than forests, which lead to higher fitness (Halliday and Blouin-Demers 2016).

We conducted this study partly because eastern Ontario is a part of the range of *T. sirtalis* that is underrepresented in the literature. Studying habitat use by free-ranging *T. sirtalis* in open habitats expands on our previous work studying habitat selection between field

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and forest habitats in large enclosures (Halliday and Blouin-Demers 2015, 2016; Halliday *et al.* 2015). Our main goal was to test two competing, but not mutually exclusive, hypotheses: (1) habitat selection by garter-snakes is driven by frog abundance and (2) habitat selection by garter-snakes is driven by the need to thermoregulate. More specifically, we first wanted to determine if habitat use by *T. sirtalis* was related to frog abundance in different habitats and we predicted that garter-snakes should be more abundant where frogs are more abundant. Food is often considered a very important aspect of habitat quality (Kennedy and Gray 1993), but this might not be the case for snakes because most eat large meals infrequently (Shine 1986). Yet some studies with snakes have suggested that habitat use may be driven by food abundance (Robertson and Weatherhead 1992). Habitat quality for snakes is often linked to structural characteristics of habitats that allow them to thermoregulate or to hide (Blouin-Demers and Weatherhead 2001; Halliday and Blouin-Demers 2015, 2016). Therefore, we also wanted to determine if habitat use by *T. sirtalis* was related to structural characteristics of the different habitats, and we predicted that garter-snakes should be more abundant in more open habitats because these have higher thermal quality in temperate regions (Blouin-Demers and Weatherhead 2001; Row and Blouin-Demers 2006; Halliday and Blouin-Demers 2016).

Methods

Study site and data collection

In June 2014, we set up six study grids in the Stony Swamp sector of the National Capital Greenbelt in Ottawa, Ontario (45.283°N, 75.817°W; Figure 1). Vegetation characteristics were variable both among and within grids, varying from cattail (*Typha* sp.) dominated to mixes of shrub, grass, and forb. Each study grid was 100 × 100 m and we separated each grid into 25, 10 × 10 m sectors, marking the corners of each sector with bamboo poles marked with flagging tape. We placed a 60 × 60 cm cover object in the centre of each sector on substrate without standing water. In general, cover objects are a useful tool to monitor snakes (Halliday and Blouin-Demers 2015; Retamal Diaz and Blouin-Demers 2017). Cover objects were made of either tin (12 of 25 sectors) or plywood (13 of 25 sectors), which have been shown to be equally effective to sample small snakes in our area (Retamal Diaz and Blouin-Demers 2017).

We monitored each grid up to six times per year, but no more than once per week, between June and August of 2014 and 2015. More specifically, we visited grids 1 and 2 six times, grid 6 eight times, grids 3 and 5 nine times, and grid 4 ten times. When monitoring a grid, three to four people walked back and forth across the grid with an even spacing (~2 m between individuals) and at a constant pace. While searching for snakes and frogs, we looked under each cover object once during

each survey, carefully looked in and around natural cover objects such as coarse woody debris without disturbing the habitat, and looked in the dense vegetation. When we detected a snake (either under a cover object or in the open), we worked together to capture the snake by hand. After catching each snake, we marked its ventral scales with a unique code using a medical cautery unit (see method and rationale in Winne *et al.* 2006). We also determined the sex of each snake and measured its snout-vent length and mass. We recorded which grid and sector the snake was caught in and released each snake at its point of capture. While monitoring each grid, we also counted the number of frogs (identified to species) encountered in each sector of each grid as a metric of food abundance; frogs are one of the main food sources for *T. sirtalis* (reviewed in Halliday 2016).

We characterized the habitat features in each sector of each grid based on the dominant vegetation class (cattail, dominant tree species, fern, forb, grass, horsetail, shrub), maximum height of vegetation, percent of sector covered by standing water, and maximum depth of water in the sector. We recorded up to two dominant vegetation classes in each sector if the vegetation was mixed.

Analyses

We tallied the number of snakes and frogs of each species encountered in each sector of each grid during each year of our study. For snakes, this tally is the number of individuals in each sector, while for frogs this tally is the number of frogs detected in each sector. We only had one recapture of a snake in the same sector, and we only counted that individual once within that sector. We encountered Common Gartersnake, Northern Watersnake (*Nerodia sipedon*), Red-bellied Snake (*Storeria occipitomaculata*), Eastern Milksnake (*Lampropeltis triangulum*), Green Frog (*Lithobates clamitans*), Northern Leopard Frog (*Lithobates pipiens*), Spring Peepers (*Pseudacris crucifer*), and a juvenile Eastern Newt (*Notophthalmus viridescens*); however, we encountered only enough *T. sirtalis* and *L. pipiens* for statistical analysis (Table 1). Despite our large array of cover objects, we only caught two *T. sirtalis* under covers, although we did catch all *S. occipitomaculata* and all *L. triangulum* under the covers.

We pooled *T. sirtalis* and *L. pipiens* abundances across surveys and converted each into a binary presence/absence variable of a species in each sector of each grid during each year. We then analyzed the presence/absence of *T. sirtalis* and *L. pipiens* within a sector using general linear mixed effects models with a binomial distribution in R (package lme4; function glmer; Bates *et al.* 2015). We built models with different combinations of the following fixed effects: presence/absence of each vegetation class, vegetation height, percent water, water depth, presence/absence of *L. pipiens* (only for the analysis of *T. sirtalis*), and year. We used grid ID as a random effect in all models. We compared models with different fixed effects using Akaike Information



FIGURE 1. Layout of grids at study site in eastern Ontario, Canada. Map data © Google Canada.

TABLE 1. Abundance of snakes and amphibians encountered (number of unique individuals for snakes, but not necessarily for amphibians) in each year of a habitat selection study in six, 1-ha study grids near Ottawa, Ontario in 2014 and 2015.

Scientific name	Common name	2014	2015
<i>Lampropeltis triangulum</i>	Eastern Milksnake	1	1
<i>Nerodia sipedon</i>	Northern Watersnake	2	1
<i>Storeria occipitomaculata</i>	Red-bellied Snake	9	2
<i>Thamnophis sirtalis</i>	Common Gartersnake	20	36
<i>Lithobates clamitans</i>	Green Frog	7	4
<i>Lithobates pipiens</i>	Northern Leopard Frog	142	18
<i>Notophthalmus viridescens</i>	Eastern Newt	1	0
<i>Pseudacris crucifers</i>	Spring Peeper	3	7

Criterion (AIC; package stats; function AIC; R Core Team 2016) and selected the model with the lowest AIC as the final model; we considered models within 2 AIC units of the best model to be competing models and used model averaging to determine effect size (Burnham and Anderson 2002). We conducted all analyses in R version 3.3.0 (R Core Team 2016).

We conducted a second analysis of the abundance of both *T. sirtalis* and *L. pipiens* based on the total number of individuals encountered on each grid during each survey. For this analysis, abundance is the number of unique *T. sirtalis* encountered. This is likely also the number of unique *L. pipiens* counted because our unit of replication is a single survey event in a grid where

it is highly unlikely that we would count the same frog twice. We used general linear models with a Poisson distribution (package *stats*; function *glm*) with the abundance of *T. sirtalis* or *L. pipiens* as the dependent variable and with year and grid identification as the independent variables. In the analysis of *T. sirtalis*, we also included the abundance of *L. pipiens* as an additional independent variable. We used bias-corrected Akaike Information Criterion (AICc; package *qpcR*; function *AICc*; Spiess 2014) to compare models for this analysis due to low sample size.

Finally, we compared the use of different vegetation types by *T. sirtalis* and *L. pipiens* to the availability of those vegetation types based on the methods described in Johnson (1980). We summed the number of captures and observations of each species in each dominant vegetation type during each year, and calculated the proportion of observations in each vegetation type. We then summed the number of sectors across all study grids that contained each dominant vegetation type, and calculated a proportion. We then compared use versus availability data (transformed into percent) for each species in each vegetation type in each year using χ^2 analysis in R (package *stats*; function *chisq.test*).

Results

Thamnophis sirtalis was more likely to be encountered in sectors with forbs (log odds ratio: 0.87, $z = 2.04$, $P = 0.04$) and was less likely to be encountered in sectors with grass (log odds ratio = -0.78 , $z = 2.04$, $P = 0.04$; Figure 2a, Table S1). The probability of presence of *T. sirtalis* was unaffected by all other vegetation classes. Two of our study grids (5 and 6) had significantly more *T. sirtalis* than the other four grids ($P < 0.01$; Figure 3a, Table S2). These grids had high forb coverage, medium shrub and grass coverage, low fern and cattail coverage, and were rebounding from a 2012 forest fire. *Thamnophis sirtalis* was also more abundant in 2015 than in 2014 ($z = 3.23$, $P < 0.01$). The probability of presence of *T. sirtalis* was unaffected by water coverage or depth or frog abundance. *Thamnophis sirtalis* was more likely to be found in habitats with forbs relative to their availability, and were less likely to be found in habitats with grass relative to their availability in both 2014 ($\chi^2_{12} = 76.06$, $P < 0.01$) and 2015 ($\chi^2_{12} = 44.78$, $P < 0.01$; Figure 1a, Table S3).

Lithobates pipiens was more likely to be encountered in 2014 than in 2015 (log odds ratio = -2.39 , $z = 5.23$, $P < 0.01$; Table S4), but their presence was unaffected by all vegetation classes (Figure 2b, Table S4). Two of our study grids (5 and 6) again had significantly more *L. pipiens* than other grids (Figure 3b, Table S5). According to the use-availability analysis, *L. pipiens* used habitats with forbs more than expected based on their availability, and used habitats with shrubs much less than expected based on their availability in both 2014 ($\chi^2_{12} = 55.82$, $P < 0.01$) and 2015 ($\chi^2_{12} = 70.04$, $P < 0.01$; Figure 2b, Table S3).

Discussion

Our study demonstrates that vegetation structure is an important predictor of habitat selection by *T. sirtalis*, but *L. pipiens* abundance is not. These results support our second hypothesis (habitat selection for thermoregulation), but do not support our first hypothesis (habitat selection for food). Our previous work (Halliday and Blouin-Demers 2016) demonstrated the importance of vegetation structure and habitat selection for thermoregulation at a coarse scale, where gartersnakes used warm open field habitat much more than cool forested habitat. In this study, we demonstrate that *T. sirtalis* prefer certain types of open habitats at a finer spatial scale. Specifically, we found more *T. sirtalis* near forbs (i.e., flowering plants like clover and vetch) more than expected based on availability, and fewer in grassy habitat than expected based on availability. Areas with high coverage of forbs were typically quite dry and offered good sites for basking. This forb habitat was also most abundant in sites 5 and 6 and is unique in the area due to a recent forest fire (summer 2012). Sites 5 and 6 had many fallen cedar trees, which provided potential cover where snakes could hide, mixed with plenty of small open sites for basking. We were able to observe snakes under these fallen trees without disturbing the habitat because the trunks were kept elevated from the ground by remaining branches. Although our use versus availability analysis did show a common preference for forbs by both *T. sirtalis* and *L. pipiens*, our analysis examining the influence of *L. pipiens* on *T. sirtalis* habitat selection demonstrated that the abundance of *T. sirtalis* in both grids and sectors of grids was unrelated to the abundance of *L. pipiens*. The exact sectors within grids where frogs were found did not coincide with the sectors where we found snakes. This suggests that, at a fine scale, *T. sirtalis* are not more likely to be found in locations where *L. pipiens* is found, despite this apparent shared habitat preference.

We found no effect of *L. pipiens* abundance on *T. sirtalis* habitat use, but this may be due to the low abundance of frogs in 2015 (Table 1). Indeed, habitat selection by *L. pipiens* is strongly related to moisture content in the soil (Blomquist and Hunter 2009). Whereas 2014 was a very wet year, 2015 was a very dry year, which likely influenced the abundance of *L. pipiens* that we encountered on our grids. Although it has been suggested that habitat use by snakes might be linked to amphibian presence (Robertson and Weatherhead 1992), other evidence suggests that daily habitat use by snakes is not linked to food abundance because snakes generally eat infrequently and are not limited by food (Halliday and Blouin-Demers 2017). Long-term data with a much larger sample size would be required to truly test this hypothesis given the low abundance of snakes and the large fluctuations in frog abundance from year to year. Frogs are also just one food source for *T. sirtalis*; their second most consumed food is earthworms, and their third through fifth most consumed food items are sal-

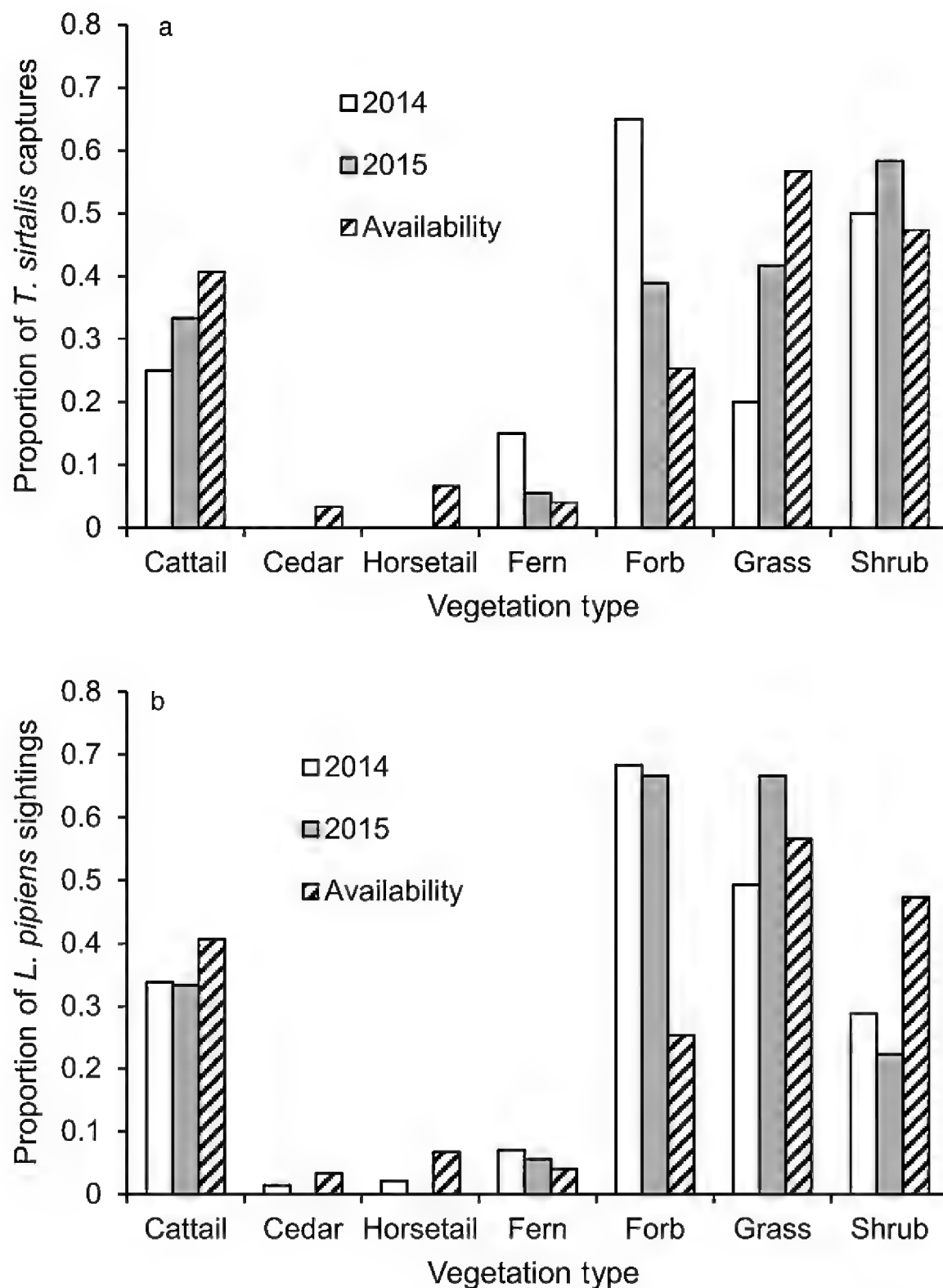


FIGURE 2. The proportion of captures of Common Gartersnakes (*Thamnophis sirtalis*; a) and sightings of Northern Leopard Frogs (*Lithobates pipiens*; b) in 1-ha study grids with different vegetation types in 2014 (white bars) and 2015 (grey bars) near Ottawa, Ontario, Canada. Hatched bars represent the proportion of sectors from all grids with each vegetation type (availability).

amanders, fishes, and small mammals (reviewed in Halliday 2016). Therefore, to truly test the hypothesis that food abundance is important in habitat selection, future studies should track the abundance of these other prey items in relation to the habitat selection of *T. sirtalis*. If *T. sirtalis* only spend a small amount of time hunting and eating prey, then the overall habitat selection that we observed would not reflect their choice for hunting. Radio-telemetry studies, along with detailed information on the activities being performed in different habitats, is crucial for understanding the reasons that *T. sirtalis* use different habitats.

The presence of water was not important to the habitat use of *T. sirtalis* in this study. This is despite water

being important in previous habitat selection studies of *T. sirtalis* (Charland and Gregory 1995; Ernst and Ernst 2003), where they avoided deep water, but were still found in close proximity to water. Water levels in our study differed drastically in space and time. 2015 was a very dry year, and all of the water on a few grids completely disappeared by the end of August. In 2014, water levels remained high for the entire season. Given the few snake captures, this made it difficult to detect a water effect.

Detection probability of snakes and frogs likely differed between different vegetation classes. For instance, tall cattails limited our ability to detect snakes to within 2 m, whereas we could detect snakes farther away in

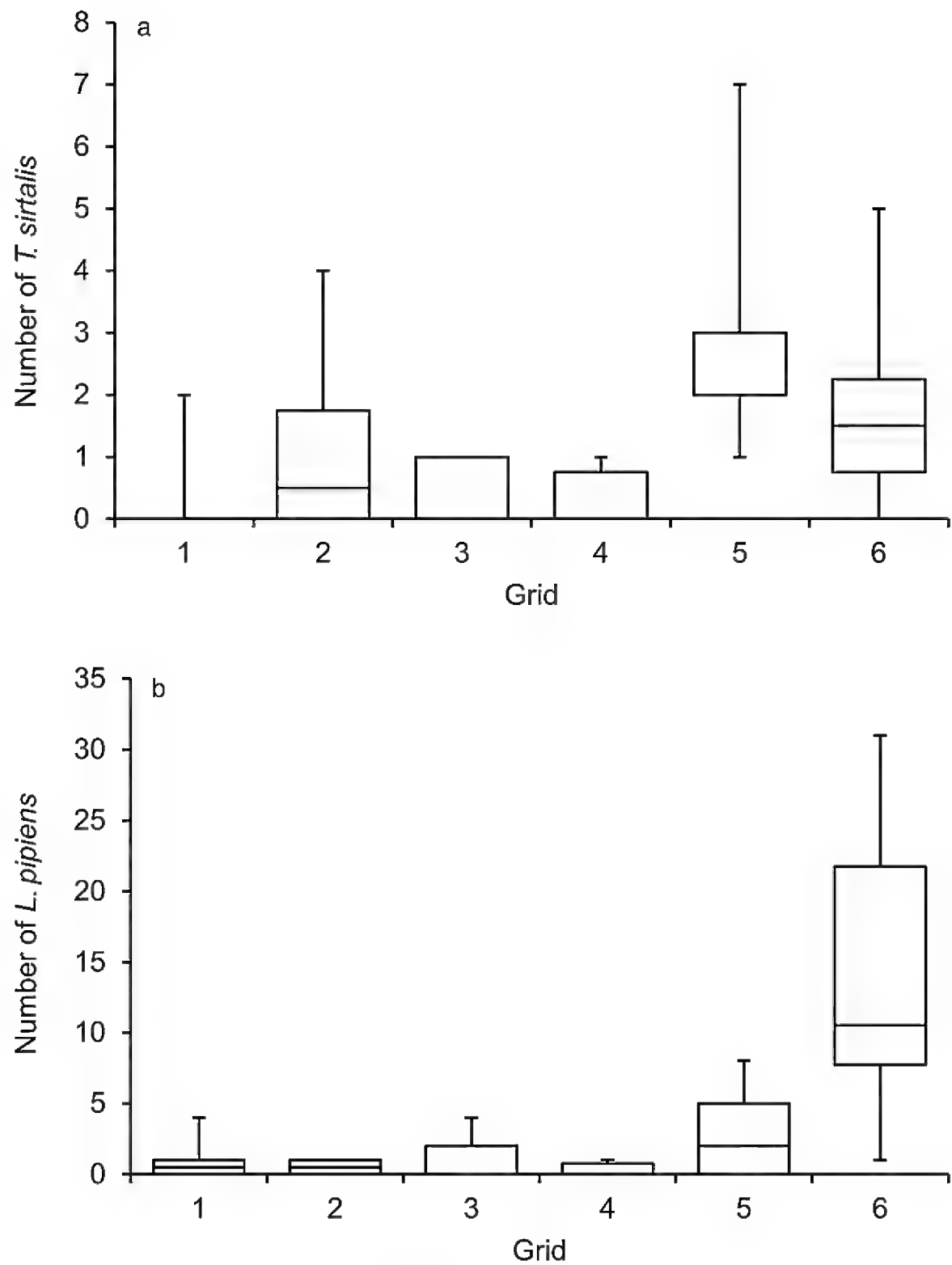


FIGURE 3. The number of Common Gartersnakes (*Thamnophis sirtalis*; a) and Northern Leopard Frogs (*Lithobates pipiens*; b) captured on each 1-ha study grid during each survey in 2014 and 2015 near Ottawa, Ontario, Canada. The line within the box is the median, the box represents the interquartile range, and the whiskers represent minimum and maximum values.

habitats with low vegetation. Snakes also effectively hid in tall grass, but tended to flee these areas when we approached, making it easier to detect them. It is therefore possible that this detection bias between habitats affected our results. However, regardless of habitat type, we kept a 2 m spacing between individuals for all surveys, and therefore did not rely on being able to detect snakes at long distances. Although this would not fully remove any potential bias, it should have helped to minimize detection bias between habitats. Future studies could use radio-telemetry to measure habitat selection by *T. sirtalis* in these habitats, and could also estimate observation bias by estimating the ability to visually find a radio-tagged snake in these habitats. Radio-telemetry

also comes with its own biases, however, related to generally small sample sizes, limits on the size of snakes that can be studied, and issues related to implanting or affixing transmitters to snakes. We therefore recommend using data from a combination of methods, including visual surveys like ours and radio-telemetry.

In conclusion, vegetation structure is important to the habitat selection of *T. sirtalis*, likely because of its effect on microhabitat quality for activities like basking and hiding. *Lithobates pipiens* abundance and water cover were not important to the habitat selection of *T. sirtalis* in our study, but long-term data would be required to truly test the importance of these factors in

habitat selection due to their high variance within and between years.

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SUPPLEMENTARY MATERIAL:

<p>TABLE S1. Model selection and final model output for general linear mixed effects models examining the presence/absence of Common Gartersnakes (<i>Thamnophis sirtalis</i>; Ts) based on habitat features and the presence/absence or abundance of Northern Leopard Frogs (<i>Lithobates pipiens</i>; Lp).</p>
<p>TABLE S2. Model selection and final model output for general linear mixed effects models examining the abundance of Common Gartersnakes (<i>Thamnophis sirtalis</i>; Ts) in study grids over two years near Ottawa, Ontario, Canada.</p>
<p>TABLE S3. Habitat use versus habitat availability for Common Gartersnakes (<i>Thamnophis sirtalis</i>, top) and Northern Leopard Frogs (<i>Lithobates pipiens</i>, bottom) selecting habitats near Ottawa, Ontario, Canada.</p>
<p>TABLE S4. Model selection and final model output for general linear mixed effects models examining the presence/absence of Northern Leopard Frogs (<i>Lithobates pipiens</i>; Lp) based on different habitat features.</p>
<p>TABLE S5. Model selection and final model output for general linear mixed effects models examining the abundance of Northern Leopard Frogs (<i>Lithobates pipiens</i>; Lp) in different study grids over two years near Ottawa, Ontario, Canada.</p>

First record of Eurasian Water-milfoil, *Myriophyllum spicatum*, for the Saint John River, New Brunswick

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Abstract

Eurasian Water-milfoil (*Myriophyllum spicatum* L.) is regarded by conservation practitioners as one of the most challenging invasive aquatic plants to manage. Owing to its broad tolerance to environmental conditions, vegetative propagation, and rapid establishment and growth, *M. spicatum* introductions have the potential to drastically alter macrophyte species assemblages via a loss of native species and their respective ecosystem functions. Following the discovery of a single specimen of *M. spicatum* in the Saint John River, near Fredericton, New Brunswick (Canada) we further investigated the localized distribution of this non-indigenous species. Thirteen areas were identified as potential *M. spicatum* habitat and were surveyed by wading or snorkeling. Specimens of *M. spicatum* were collected and morphological identifications were verified through genetic analyses (ITS2; *rbcLa*). The results of our investigation confirm the presence of *M. spicatum* at six different locations within the Saint John River. Here we discuss the implications of this discovery in the context of the contiguous aquatic habitats along a large river system.

Key words: Eurasian Water-milfoil; *Myriophyllum spicatum*; aquatic invasive; Saint John River

Introduction

Approximately 15% of non-indigenous plant species become invasive causing irreversible disruptions to ecosystem functions (Westbrooks 1998). In aquatic environments, not only do invasive plants alter floristic assemblages via loss of native species (Aiken *et al.* 1979; Boylen *et al.* 1999) and their respective ecosystem functions (Duffy and Baltz 1998; Thomaz and da Cunha 2010) and compromise habitat for many other species, but they also alter environmental flows, nutrient cycling, and can directly influence water quality (Zedler and Kercher 2004; Kovalenko and Dibble 2010; Villamagna and Murphy 2010). Additionally, invasive aquatic plants often grow to high densities and are detrimental to the economic, recreational, and aesthetic qualities of waterways (Newroth 1985; Eiswerth *et al.* 2000). Mitigation of the negative impacts of aquatic introductions requires active control measures and is costly (Pimental *et al.* 2004).

One of the five most noxious aquatic plant invaders of aquatic ecosystems is Eurasian Water-milfoil (*Myriophyllum spicatum* L.; Cronk and Fennessy 2001). Native to Eurasia and northern Africa (Sennikov 2016), *M. spicatum* is now present on every continent except Antarctica (Cook 1985). While the impacts of the introduction of *M. spicatum* vary in magnitude among different aquatic environments and in different regions (Smith and Barko 1990), it is generally acknowledged among scientists and conservation practitioners that this species frequently establishes dense, monospecific beds that outcompete local flora and reduce the diversity and abundance of native species (Grace and Wetzel 1978; Madsen *et al.* 1991; Boylen *et al.* 1999). In some in-

stances, this species has outcompeted native flora in as little as 2–3 years (Aiken *et al.* 1979; Newroth 1985; Boylen *et al.* 1999). Considered the most widely managed invasive aquatic plant in the United States (Bar-todziej and Ludlow 1998), *M. spicatum* is on several regional invasive species watch lists and is listed as one of the ten most unwanted species in Maine, USA (Hill and Williams 2007), and New Brunswick, Canada (New Brunswick Alliance of Lake Associations website: <http://www.nbala.ca/new-page-1>).

The vector and timing of introduction of *M. spicatum* to North America is not completely understood. While Couch and Nelson (1985) suggest *M. spicatum* was introduced to North America in the 1940s, Reed (1977) reviewed historical herbarium specimens and provided evidence that the earliest verified records of *M. spicatum* from North America are dated back to at least 1881 but acknowledged that the introduction was possibly as early as 1848. It is not uncommon for non-indigenous species to exhibit an initial lag in their growth before they become invasive, and many non-indigenous aquatic plant introductions go unnoticed until they are established as truly invasive. Thus, it is highly probable that *M. spicatum* was present in North America as early as 1848 and Couch and Nelson's (1985) report regarding introduction in the 1940s more accurately reflects the timing at which this species was first observed as invasive.

In an assessment of historical records for the distribution of *M. spicatum* in North America, Reed (1977) also observed a disjunct distribution with populations in eastern North America, southeastern North America, and an isolated region in California. He attributed this dis-

junction to independent introductions that were most likely a consequence of the release of aquarium plants, as various species of *Myriophyllum* were commonly cultured and distributed for the aquarium trade at this time (Reed 1977). While the release of aquarium plants may be the original source of introduction events across North America, introduction to new waters is now primarily attributed to fragments introduced by boats and their associated trailers (Johnson *et al.* 2001; Rothlisberger *et al.* 2010).

Successful eradication of recently established invasive species populations is highly dependent on rapid detection and prompt management actions (Willby 2007). Two factors may hinder the rapid detection of *M. spicatum*: difficulty in detection because it is primarily beneath the water's surface and difficulty in identification versus similar native congeners (especially the sister species Siberian Water-milfoil, *M. sibiricum* Komarov) because the key morphological features vary with phenotypic plasticity (Strand and Weisner 2001) and/or hybridization (Sturtevant *et al.* 2009).

While conducting macrophyte surveys for 171 sites along the Saint John River (SJR) as a part of a larger aquatic ecosystem study, the Mactaquac Aquatic Ecosystem Study (<http://canadianriversinstitute.com/research/mactaquac-aquatic-ecosystem-study/>), we discovered a single inconspicuous specimen of *M. spicatum*. Prior to our discovery of this species in the SJR, Hinds (2000) reported that this species had been collected from a small pond in Fundy National Park (Hinds 2000: 667). The introduction of *M. spicatum* to the SJR poses a threat to the submerged aquatic flora within the river and associated waterways. To assess the local distribution of this non-indigenous species, we used an active survey approach that involved snorkelling surveys of potential habitat and molecular approaches (DNA analyses) to verify our taxonomic identifications.

Methods

To identify potential *M. spicatum* habitat for this survey we looked for areas in the Fredericton region of the SJR (where the first specimen was initially collected) that were consistent with habitat conditions reported for this species (Aiken *et al.* 1979). Our survey emphasized sheltered cove environments or other low flow areas with soft substrate, as well as areas with frequent boat traffic (Figure 1). Where necessary, snorkelling surveys were conducted to ensure we could observe the submerged flora.

Apical portions of plants morphologically identified in the field as *M. spicatum* were collected and preserved as herbarium vouchers stored at the Connell Memorial Herbarium (UNB IH) at the University of New Brunswick (Table 1). Leaf tissue sub-samples were dehydrated in silica for subsequent genetic analyses (Fazekas *et al.* 2012). Dehydrated tissue was sent to the Canadian Centre for DNA Barcoding (CCDB) for DNA extraction, PCR amplification, and sequencing according to CCDB

standardized protocols (Fazekas *et al.* 2012). To facilitate comparison of our genetic results with taxonomic data available in GenBank (NCBI Resource Coordinators 2016) and the Barcoding of Life Data System (Ratnasingham and Hebert 2007) we selected two standard land plant DNA barcode markers, *rbcLa* and ITS2 (Fazekas *et al.* 2012).

Results and Discussion

Analyses of ITS2 and *rbcLa* sequence data was consistent with the morphological-based identification of *M. spicatum* at six of 13 sites surveyed (Table 1). Four of the six sites where *M. spicatum* is present had only a few scattered plants (Table 1). The remaining two sites where this species was found had patches where it was clearly established as dense macrophyte beds (Figure 2). To assess the potential future impact of this introduction on the native aquatic flora, we reviewed what has been reported for the biology of this invasive species and considered what risks this may present for the aquatic environments along the SJR.

Reproduction

Myriophyllum spicatum shoots emerge and exhibit rapid growth from an overwintering rhizomatous mass in the early spring and throughout summer. As the growing season progresses, plant growth peaks at the water surface where stems are highly branched forming dense floating canopy (Titus *et al.* 1975). Vegetative portions of the plants break off throughout the growing season and in the fall when plants typically die back to the propagating rhizome crowns (Aiken *et al.* 1979).

Fragmented vegetative portions are the primary mode of reproduction and spread for *M. spicatum* within an aquatic ecosystem (Kimbel 1982). In the SJR, downstream spread of this species via vegetative fragmentation is naturally facilitated by peaks in hydrological flows, as well as seasonal ice scouring. The spread of *M. spicatum* between watersheds is largely attributed to vegetative material transported by boat motors and trailers (Johnson *et al.* 2001; Rothlisberger *et al.* 2010). In the Fredericton region of the SJR where we have confirmed the presence of *M. spicatum*, further spread by boat motors is a concern as this area is frequently used by recreational boaters. Consequently, this increases the potential of the species to move in larger, discontinuous jumps, enabling the species to spread upstream and to new water bodies.

Like many successful invasive species, *M. spicatum* has multiple modes of reproduction and frequently exhibits sexual reproduction in addition to vegetative fragmentation. Perhaps more concerning than the ability to undergo both asexual and sexual reproduction, is the ability of *M. spicatum* to hybridize with its native sister species *M. sibiricum* to produce plants that exhibit "hybrid vigor"—plants with competitive phenotypes that are superior to both parent species (Moody and Les 2002, 2007; Sturtevant *et al.* 2009). This hybridization, between an introduced invasive species and a native

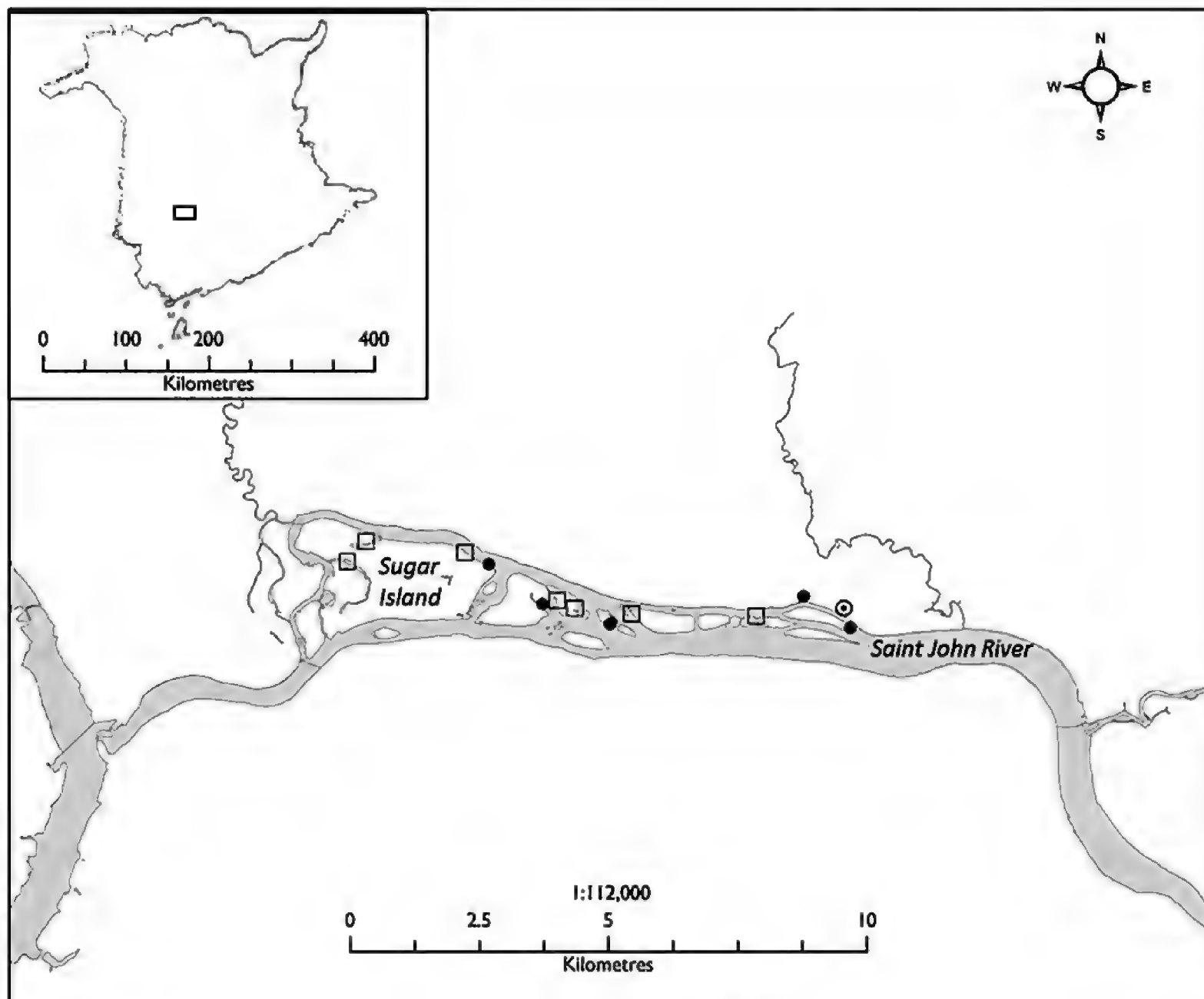


FIGURE 1. Six sites within the Fredericton region of the Saint John River where specimens of Eurasian Water-milfoil (*Myriophyllum spicatum*) were collected and identified (denoted by “●”). ⊙ = original site of collection; □ = potential *M. spicatum* habitat investigated but species was not present.

species, can result in “genetic pollution” introducing new alleles to the population and potentially wiping out locally adapted genotypes (Laikre *et al.* 2009). In New Brunswick, the native species *M. sibiricum* is classified as potentially vulnerable (S3/S4) and is widespread on the lower SJR system (S. Blaney pers. comm. February 2015). Thus, the ecological risks posed by the potential hybridization of *M. spicatum* and *M. sibiricum* are two-fold: hybridization may give rise to populations that exhibit hybrid-vigor and promote further colonization and populations of the native species, *M. sibiricum*, may be put at risk due to genetic pollution or competition pressure with *M. spicatum* or *M. spicatum* × *M. sibiricum* hybrids.

Habitat and area for potential colonization

Most commonly establishing in water with depth ranging 1–3 m, *M. spicatum* has been reported as deep as 10 m (Aiken *et al.* 1979), reaching 7 m high. Plants thrive in eutrophic lakes with soft organic substrates but persist in a wide range of substrates and environmental conditions (Nichols and Shaw 1986). With regard to water quality, *M. spicatum* is able to persist in a wide pH

range (5.4–11), tolerate salinity up to 15 ppt, and tolerate various industrial pollutants (Aiken *et al.* 1979; Wang *et al.* 1996). When growing in shallow areas susceptible to drops in water level that may leave it exposed, *M. spicatum* assumes a terrestrial form allowing it to gradually become stranded and survive (Aiken *et al.* 1979). The broad environmental tolerance in this species enables it to colonize various types of lakes, wetlands and salt marshes, or river margins, coves, and inner island channels as observed in our surveys. Downstream of our confirmed *M. spicatum* population is approximately 130 km of river with extensive seasonal flood plain and contiguous habitat that has high potential for colonization by this species.

The Grand Lake Meadows (GLM), located approximately 40 km downstream from the sites of the *M. spicatum* occurrence, is the largest freshwater wetland and floodplain in New Brunswick. It includes the provincial Grand Lake Class II Protected Natural Area (GLPNA). Recent surveys of the flora in the area report 98 rare species that contribute 20% of the total flora (Papoulias *et al.* 2006). One of the taxa reported, Budding

TABLE 1. Eurasian Water-milfoil (*Myriophyllum spicatum*) specimens and associated collection and GenBank records.

UNB IH accession (research specimen number)	Collectors	Location	Collection date	Habitat	Abundance	GenBank accession number	
						ITS 2	<i>rbcLa</i>
66290 (MRB0000031)	M. Bruce C. Brooks Z. Compson S. Andrews	45.97577°N, 66.68854°W	20 August 2015	Edge of back channel, soft bottom, water ~60 cm at time of collection	Single small plant	MG648683	MG648689
66921 (MRB0000034)	M. Bruce H. Johnson G. Filloramo	45.97711°N, 66.69473°W	4 July 2016	Sheltered, soft substrate	Dense patch (~4 m × 5 m) surrounded by several peripheral plants	MG648684	MG648690
66292 (MRB0000035)	M. Bruce S. Andrews	45.97552°N, 66.75940°W	16 July 2016	Sheltered island inlet, soft substrate, water ~120 cm at time of collection	Numerous scattered plants	MG648686	MG648692
66293 (MRB0000036)	M. Bruce H. Johnson G. Filloramo	45.98299°N, 66.77400°W	16 July 2016	Sheltered island inlet, soft substrate, water ~180 cm at time of collection	Dense patch in center of cove, ~2 m × 3 m	MG648685	MG648691
66293 (MRB0000037)	M. Bruce B. Pardy	45.972010°N, 66.68262°W	4 July 2016	Small cove on back channel, soft substrate, water ~90 cm at tie of collection	A few plants	MG648687	MG648693
66294 MRB0000039	M. Bruce S. Andrews Z. Compson	45.97290°N, 66.74338°W	4 September 2015	Edge of island, mixed substrate, water ~60 cm at time of collection	Single small plant	MG648688	MG648694

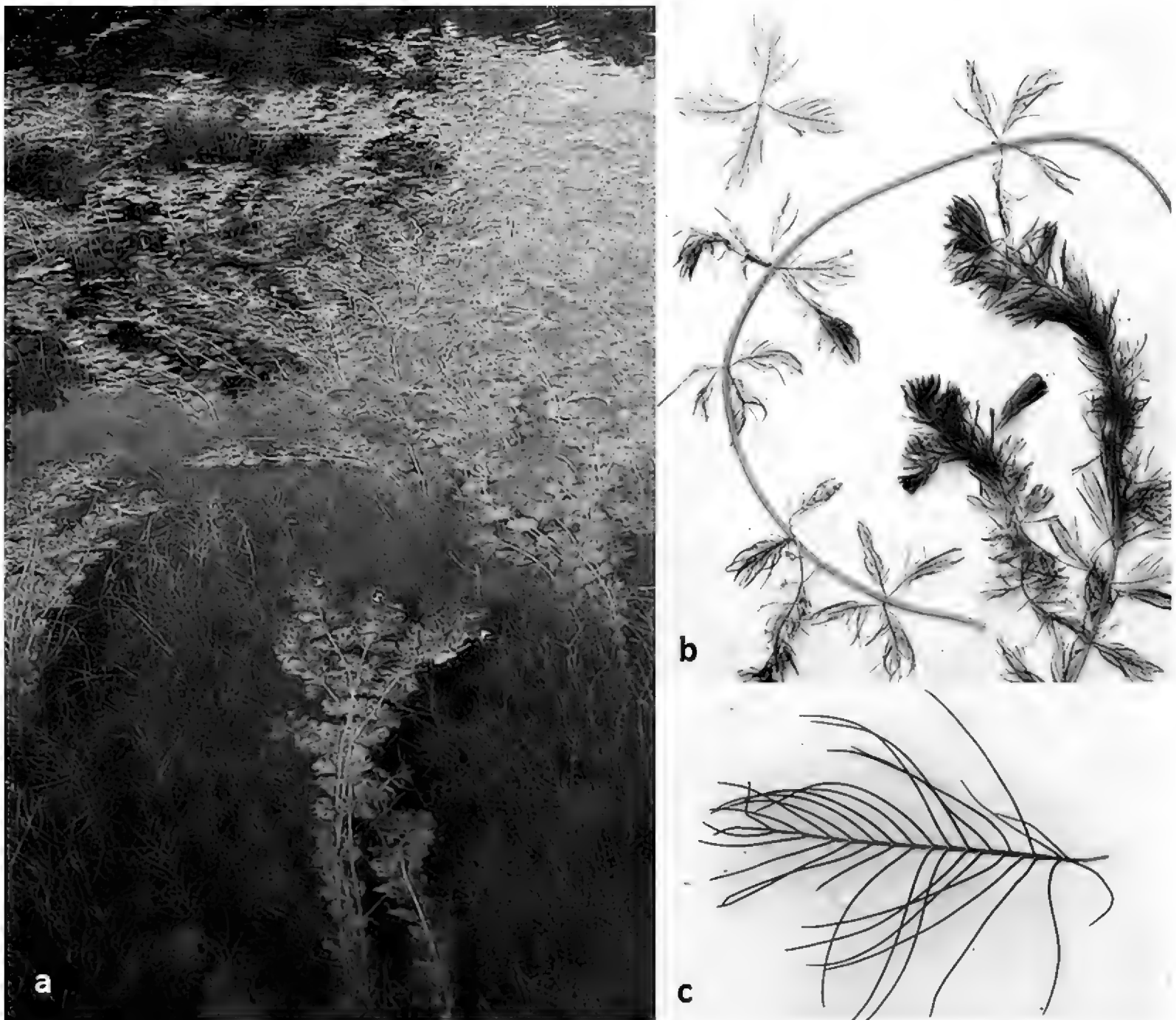


FIGURE 2. Eurasian Water-milfoil (*Myriophyllum spicatum*). a. Overall habit, plants growing in a dense patch with a high degree of branching, forming a canopy at the water surface. b. Specimen of *M. spicatum* showing leaves in whorls of four along stem. c. Single pectinate leaf with 15 pairs of pinnae. Photos: M. Bruce.

Pondweed, *Potamogeton berchtoldii* subsp. *gemmiparus* (J.W. Robbins) Les & Tippery, is the only known record of this species for New Brunswick and it is rare on the national level (Papoulias *et al.* 2006). In the spring, the SJR floodplain spills into the GLM and GL PNA, downstream of our confirmed populations of *M. spicatum*. The GLM and the GL PNA is thus an area of special concern that should be monitored for a potential *M. spicatum* invasion.

Options for controlling further spread

Early detection of *M. spicatum* and minimizing risk of further spread of early introductions hold the most promise for aquatic ecosystem management (Willby 2007). For individual plants, or small stands of *M. spicatum*, shading with a black cloth that inhibits photosynthesis can kill the plants (Bailey and Calhoun 2008). This could be an option for the plants that were found in this study, or small isolate populations in other areas. Another option that may be useful (for at least this area

of the SJR) is to reduce water flow when air temperatures drop to freezing in early winter. Exposing the crown of the plant to freezing temperatures has shown some success in managing populations of this species in other areas (Bates and Smith 1994; Wagner *et al.* 2008). Considering that our observed plants were all in shallow areas below the Mactaquac Hydrogeneration Station (MGS) which have been observed to be exposed at times when the MGS retains water (M.B. pers. obs. early August 2015 and 2017), this could be an option for managing the small populations in this area. Where *M. spicatum* has established as invasive, raking of vegetation helps to temporarily reduce biovolume; however, reproductive fragments render application of this method as high-risk for further spread. Herbicides and the introduction of natural pests have also shown some promise, although the previous studies do not assess potential negative impacts to non-target native species within the aquatic ecosystem (Creed 1998; Cock *et al.* 2008).

Conclusions and future investigations

With knowledge of the presence of this non-indigenous species within the SJR, we intend to quantitatively assess the amount of potential downstream habitats available for colonization by developing spatial models of potential habitat. Spatial models have been used in a number of ecological and biological studies to identify links between the abiotic and biotic environment (e.g., Milhous *et al.* 1981; Milhous 1999). Such models use environmental variables, such as velocity, substrate composition, temperature, etc., to explain the presence and spatial distribution of biota of interest (e.g., Dunbar *et al.* 2011). We intend to build a spatial model to (a) identify habitat utilized by *M. spicatum* and (b) apply our model to the SJR to identify areas that may potentially be available for colonization.

Unfortunately, we currently cannot ascertain when or how this species arrived, or the full extent of this species' range in the SJR. Our immediate priority is to extend our survey coverage and to determine if *M. spicatum* is present beyond the range we have observed. Prior to the recreational boating season, we will engage local conservation practitioners and develop an action plan to educate and engage the public as to the presence of *M. spicatum* in this region in an effort to minimize the further spread of this species and mitigate the negative effects of already established occurrences.

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Manitoba's endangered alvars: an initial description of their extent and status

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Abstract

Alvars are rare in Canada and uncommon globally. This study represents the first formal attempt to describe and delineate the extent of alvars in Manitoba. A systematic examination of the Interlake region's edaphic and biological characteristics, using a geographic information system, resulted in the identification of 67 sites warranting further field study. Of these sites, 61 were surveyed and information was collected on vegetation composition and structure, soil characteristics, land ownership, and land use. Alvar was confirmed at 28 sites, extending over approximately 3930 ha in five geographically distinct clusters. Four putative types of alvar communities are described: grassland, shrubland, savannah, and wetland. Livestock grazing is the dominant land use and occurs across more than three-quarters of Manitoba alvar. Approximately 12% coincide with mining claims or quarry leases. Two-thirds occur on publicly owned land.

Key words: Alvar; karst; endangered ecosystem; Manitoba; Interlake; limestone; dolomite

Introduction

Alvars are globally uncommon ecosystems that are distinctive for their unusual plant species composition and associations and natural openness in otherwise forested regions (Catling and Brownell 1995; Reshcke *et al.* 1999), although alvar woodlands and the associated successional stages are also important components (Catling and Brownell 1999a; Catling *et al.* 2002; Brunton and Catling 2017). Alvars have thin or absent soils underlain by flat limestone or dolomitic bedrock that restricts drainage; thus, they are subject to extreme variations in moisture availability that range from drought conditions to periodic flooding (Brunton 1988; Catling and Brownell 1995; Reschke *et al.* 1999; Catling 2009a). The physical structure and species composition of alvar plant communities can vary; Great Lakes alvars, for example, have been differentiated into 13 types (Reschke *et al.* 1999). In Manitoba, alvar-like ecosystems that support species characteristic of both prairie and boreal forest, with a limited occurrence of trees and occasional exposure of dolomitic pavement, have been described (Hamel and Foster 2004).

In Canada, alvars are found in the Great Lakes region, Quebec (Reschke *et al.* 1999), and the Northwest Territories (Catling 2009a). The presence of alvar in Manitoba was noted by Catling (2009a), but no information on its extent was provided. Although the precise extent of alvars in North America is not yet known, their distribution is fragmented and loosely follows the edge of the Canadian Shield where postglacial meltwaters have exposed limestone bedrock (Catling 2009a). Before our study, alvar-like ecosystems associated with near-surface dolomitic limestone pavement and inland cliffs had been documented at five locations in Manito-

ba between the southern basins of Lakes Manitoba and Winnipeg, i.e., the Interlake region (Hamel and Foster 2004). In 2011, an Ontario alvar expert (John Riley) accompanied us to one of these locations and confirmed that the ecosystem shared characteristics consistent with alvar ecosystems in Ontario and were worthy of further study and formal description.

In 2015, the Manitoba government listed alvar as endangered under the Manitoba *Endangered Species and Ecosystems Act* using the authors' unpublished information to support determination of its conservation status.

The results of this study were previously published in a technical report (Manitoba Alvar Initiative 2012). This paper refines those results and confirms the findings in the context of the established body of knowledge on North American alvars. The objectives of this study were to survey and map alvars in the Interlake region of Manitoba; to describe their physical structure and species composition; and to determine land ownership and land uses of Manitoba alvars.

Methods

We used a geographic information system (GIS) to identify and delineate 67 sites of potential alvar encompassing 6313 ha (Figure 1) in the south Interlake and adjacent regions. We examined spatial data layers of geomorphologic and vegetative features representative of alvar-like sites identified by Hamel and Foster (2004). Layers included orthophotographs (to assess vegetation cover), soil classification data (to determine soil depth and the presence of near-surface limestone bedrock), and a digital elevation model (to identify the location of ridges; Manitoba Conservation and Water

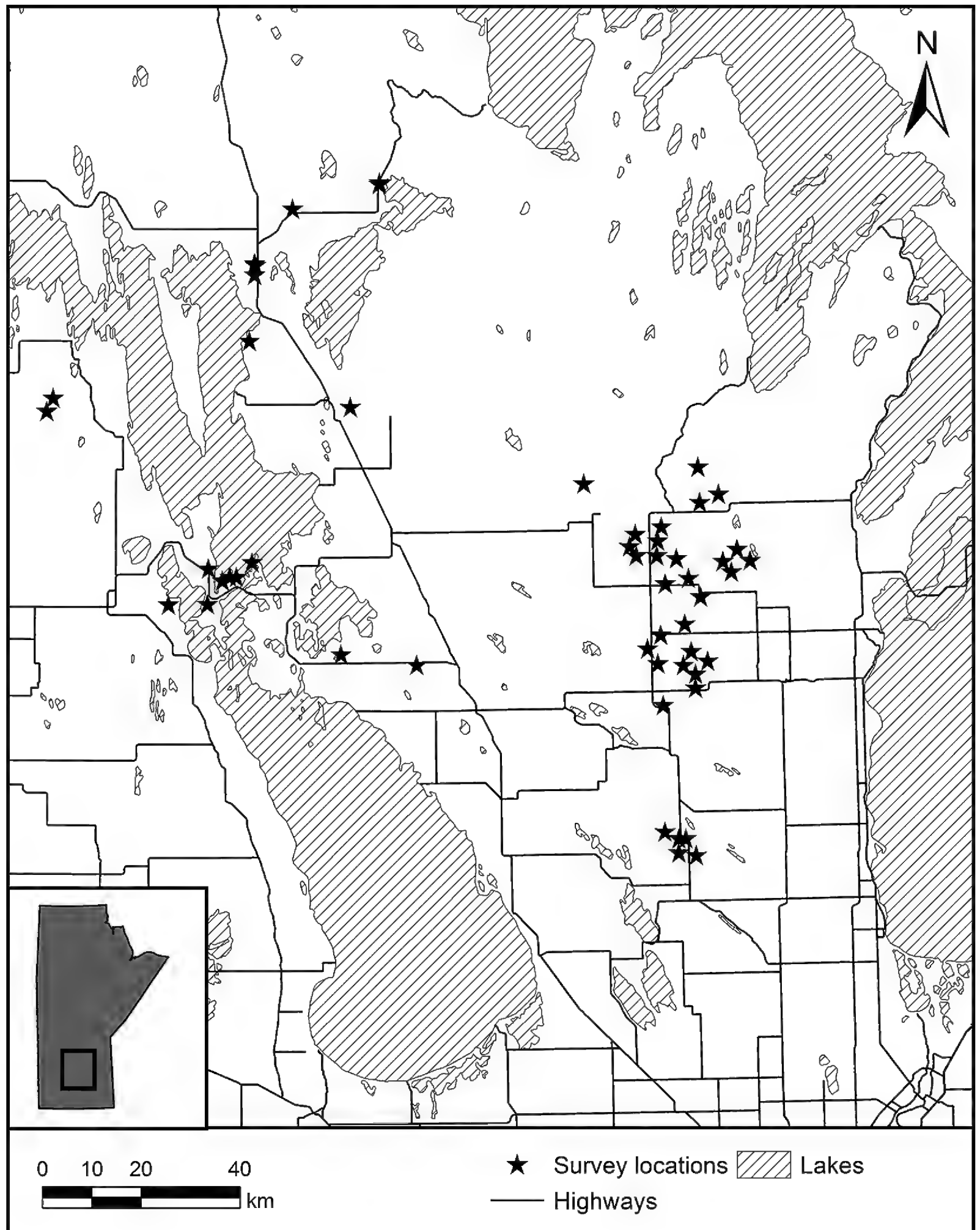


FIGURE 1. Survey locations (stars) were considered potential locations for alvar based on similarities in geological and soil characteristics to previously confirmed communities in Manitoba.

Stewardship 2012a). Between June and August 2012, we surveyed and assessed 61 sites to determine whether they supported alvar. We attempted to visit all potential sites regardless of ownership, but we did not receive permission to access six private land parcels.

A site was determined to be alvar if it met the following criteria: presence of flat limestone or dolomite bed-

rock that restricts drainage; soil thin—with a depth up to 15 cm that is not the result of mechanical removal—or absent (criterion used by Brunton 1988; Catling and Brownell 1995; Reschke *et al.* 1999); and tree canopy cover <60% (criterion used by Reschke *et al.* 1999). Although alvars can occur on soil deeper than 15 cm (Reschke *et al.* 1999), such sites were not in-

cluded in the estimation of extent for this study because they could not be confirmed as being alvars without more detailed analyses of the species composition and/or investigation of other ecologically distinct characteristics resulting from the influence of an underlying bedrock pavement.

If not visible at the surface, limestone pavement was detected by digging small test holes. We determined soil depth by pressing a metal rod into the soil and measuring depth at impact with bedrock. Evidence of extreme moisture variability was based on observations of standing water following rain events, the presence of algae on dry pavement, thin bare soil (without evidence of disturbance), and restricted vegetation and lichen growth patterns. We recorded qualitative observations of the dominant plant species, soil depth, unique topographic features, land use, and patterns of flooding, drought, and drainage.

The potential extent of alvar at each survey site was mapped as polygons in GIS. Boundaries were delineated by using ground-truthed global positioning system coordinates and interpreting orthophotographs. These maps indicate the estimated maximum extent of the alvar communities observed. Within mapped habitat patches, there may be areas without alvar, or an area may represent a mosaic of alvar and other ecosystems.

Dominant physiognomic characteristics were used to categorize alvars into types to better describe the variation observed. Alvar types were characterized first by growth form (tree, shrub, forb, or graminoid), then vertical structure (<10% tree canopy or 10–60% tree canopy, comparable to thresholds used to distinguish savannah from other upland ecosystems found in the Interlake region; Minnesota Department of Natural Resources 2005), and, finally, by wetland or upland species affinities. Putative descriptions of each type's composition and variation were prepared using the data collected during site surveys. We used vegetation survey plots at a small sample of sites to supplement the general survey data and test the accuracy of these descriptions. Nine 20 m × 50 m plots, distributed among four sites, were randomly placed in what appeared to be unique subtypes of alvar. Each plot was divided into six subplots: one 20 m × 20 m; four 10 m × 10 m; and one 20 m × 10 m. The canopy cover of vascular plants, bryophytes, and lichens was recorded by visual observation within the four 10 m × 10 m subplots using the following cover classes: <0.1%, 0.1 to <1%, 1 to <2%, 2 to <5%, 5 to <10%, 10 to <25%, 25 to <50%, 75 to <95% and ≥95%. The additional two plots were used to capture the cover class of any species not recorded in the initial four plots. Soil depth was recorded on the centre line and at 10 m and 30 m along the plot starting from the 10 m × 20 m end. Voucher specimens obtained for vascular plants, bryophytes, and lichens were deposited in the University of Manitoba herbarium (WIN). A statistical analysis was not completed.

The bedrock composition of the limestone underlying alvar was compared at each site by overlaying the mapped alvar polygons with a GIS shapefile of the geological periods of bedrock formation (Manitoba Mineral Resources 2012a) to identify patterns related to alvar type and distribution.

Results and Discussion

Extent and distribution

Alvar was found at 28 of the 61 survey locations, with a maximum extent of ~3934 ha. Alvars >16 ha often supported internal patches of non-alvar ecosystems, such as forest or prairie, where soil depth was greater than 15 cm.

We mapped 101 spatially distinct units of alvar, varying from 0.4 ha to 809 ha and grouped these units into five geographically distinct sites (Figure 2). The Marble Ridge Alvar, referred to as Marble Ridge A, B, and C Alvars, follows a limestone formation of the same name, along which inland limestone cliffs are also found. The Peguis Alvar is immediately east of the Peguis First Nation Reserve, and the Sylvan Alvar is almost completely within the boundaries of the Sylvan Dale Community Pasture. The Poplarfield Alvar represents a group of small, isolated units near Poplarfield. The Clematis Alvar is located in and around the Clematis and Sandridge Wildlife Management Areas.

Alvar types

Alvars were categorized into four putative types: grassland (graminoid dominated, <10% tree cover, upland affinity), shrubland (shrub dominated, <10% tree cover, upland affinity), savannah (shrub dominated, >10% tree cover, upland affinity), and wetland (graminoid dominated, <10% tree cover, wetland affinity). Many sites supported multiple types of alvar occurring in combination. A list of plant and lichen species observed in each alvar type is shown in Table 1, but quantitative values are not presented as the plot data are not fully representative of the variation that exists within the types described.

Grassland alvars have nearly continuous vegetative cover, with soil depth typically ranging from 5 cm to 10 cm, and only occasional patches of limestone pavement (Figure 3). They are dominated by upland graminoid species, with high forb and low shrub cover. Trees are typically absent or restricted to the periphery. Moss provides significant ground cover among and beneath other vegetation. Bare soil, exposed limestone, and bryophyte and lichen growth directly on the limestone pavement were uncommon. These sites are generally flat, although some areas have small (typically <1 m in height) outcrops along the edges of plateau formations. We observed less evidence of flooding following rain compared with other alvars, although drainage is restricted and water pools on the limestone pavement. We did not observe conditions immediately following spring melt.

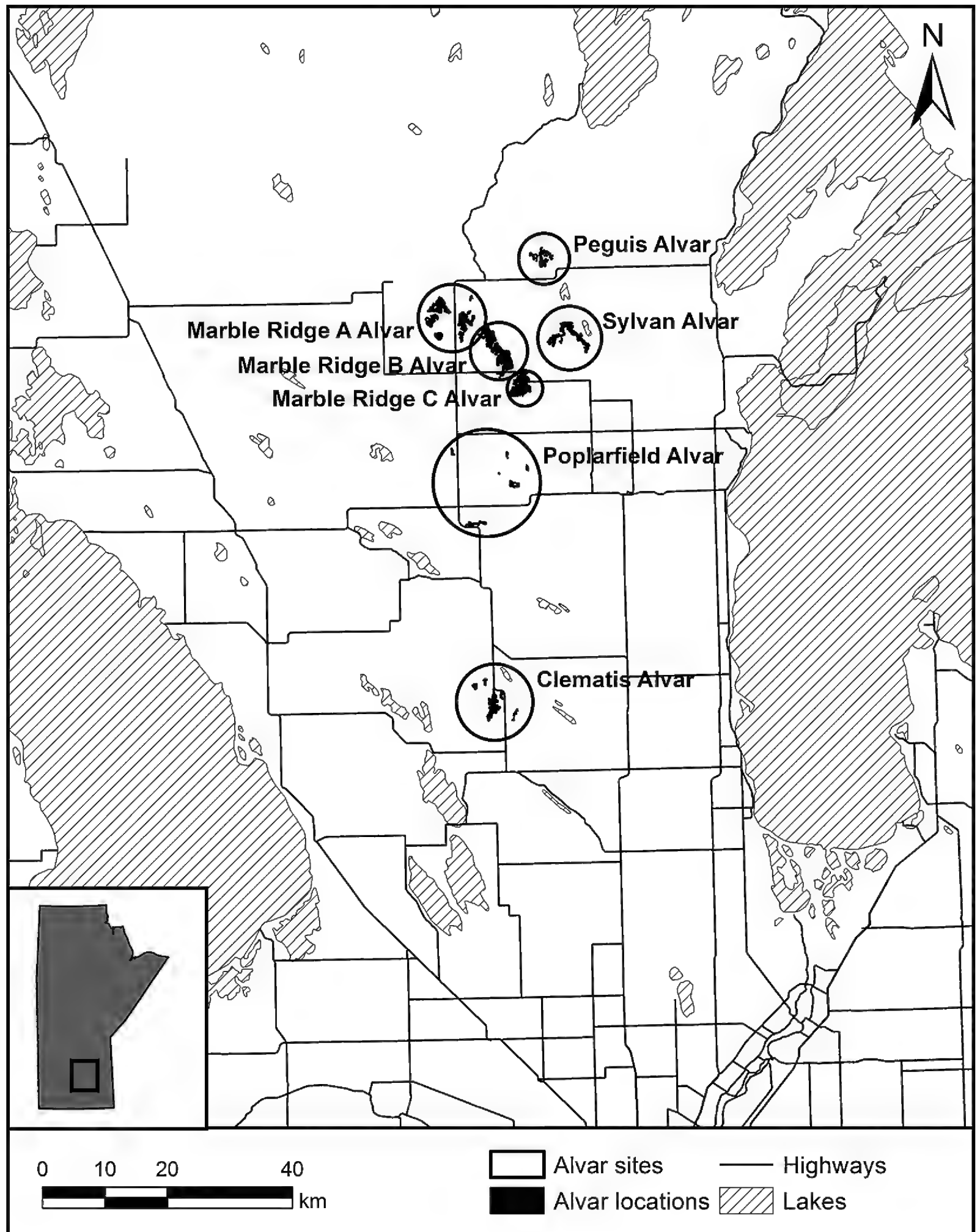


FIGURE 2. Confirmed locations of alvar in Manitoba. Individual patches of alvar have been grouped into five sites. Marble Ridge A, B, and C together constitute a single site.

In shrubland alvars (Figures 4, 5, and 6) vegetative cover is generally patchy and often restricted to cracks and seams in the bedrock with deeper soils. Soil depth is shallower than in grassland alvars, typically <5 cm, and limestone pavement is frequent. Shrubs are the

dominant vascular plant cover, followed by forbs, with graminoids frequent, but not as abundant as in grassland alvars. Tree cover is greater than in grassland alvars, but still low, and trees generally appear to be stunted. Cover of bryophytes, lichens, and bare soil is much higher

TABLE 1. Vascular plants, bryophytes, and lichens observed in each type of alvar.

Species			Conservation status*				Alvar type			
Scientific name		Common name	Global	Subnational	Grassland	Shrubland	Savannah	Wetland		
VASCULAR PLANTS										
<i>Achillea millefolium</i> L.		Common Yarrow	G5	S5	X	X	X			
<i>Agoseris glauca</i> (Pursh) Rafinesque		Pale Agoseris	G5	S4S5		X	X			
<i>Agrostis scabra</i> Willdenow		Rough Bentgrass	G5	S5		X	X			
<i>Agrostis stolonifera</i> L.		Creeping Bentgrass	G5	SNA		X	X			
<i>Allium stellatum</i> Fraser ex Ker Gawler		Autumn Onion	G5	S5	X	X	X			
<i>Allium textile</i> A. Nelson & J.F. Macbride		Prairie Onion	G5	S3		X	X			
<i>Amelanchier alnifolia</i> (Nuttall) Nuttall ex M. Roemer		Saskatoon	G5	S5		X	X			
<i>Ambrosia</i> spp.		Ragweed species			X	X	X			
<i>Andropogon gerardi</i> Vitman		Big Bluestem	G5	S5		X	X			
<i>Anemonastrum canadense</i> (L.) Mosyakin		Canada Anemone	G5	S5		X	X			
<i>Anemone cylindrica</i> A. Gray		Long-headed Anemone	G5	S5		X	X			
<i>Anemone multifida</i> Poiret		Cut-leaved Anemone	G5	S5		X	X			
<i>Antennaria</i> spp.		Pussytoes species			X	X	X			
<i>Anticlea elegans</i> (Pursh) Rydberg		Mountain Death Camas	G5	S5		X	X			
<i>Apocynum androsaemifolium</i> L.		Spreading Dogbane	G5	S5		X	X			
<i>Arabis hirsuta</i> (L.) Scopolii		Hairy Rockcress	G5	S5		X	X			
<i>Arabis</i> sp.		Rockcress species				X	X			
<i>Arctostaphylos uva-ursi</i> (L.) Sprengel		Common Bearberry	G5	S5		X	X			
<i>Artemisia campestris</i> L.		Field Wormwood	G5	S4S5		X	X			
<i>Artemisia ludoviciana</i> Nuttall		Silver Wormwood	G5	S5		X	X			
<i>Asclepias</i> sp.		Milkweed species				X	X			
<i>Betula occidentalis</i> Hooker		Water Birch	G5	S3S5		X	X			
<i>Betula papyrifera</i> Marshall		Paper Birch	G5	S5		X	X			
<i>Betula pumila</i> L.		Bog Birch	G5	S5		X	X			
<i>Bromus inermis</i> Leysser		Smooth Brome	G5	SNA		X				
<i>Bromus porteri</i> (J.M. Coult) Nash		Porter's Brome	G5	S2S3	X	X	X			
<i>Campamula gieseckeana</i> (Vest ex Shultes)		Giesecke's Bellflower	G5	S5	X	X	X			
<i>Carex</i> spp.		Sedge species			X	X	X			X
<i>Cerastium arvense</i> L.		Field Chickweed	G5	S5		X	X			
<i>Chenopodium</i> spp.		Goosefoot species				X				
<i>Cirsium drummondii</i> Torrey & A. Gray		Drummond's Thistle	G5	S4		X	X			
<i>Cirsium</i> sp.		Thistle species				X	X			
<i>Comandra umbellata</i> (L.) Nuttall		Bastard Toadflax	G5	S5		X	X			
<i>Corylus americana</i> Walter		American Hazelnut	G5	S4		X	X			
<i>Cypripedium</i> sp.		Lady's Slipper				X	X			
<i>Dalea purpurea</i> Ventenat		Purple Prairie-clover	G5	S5		X	X			
<i>Danthonia spicata</i> (L.) P. Beauvois ex Roemer & Schultes		Poverty Oatgrass	G5	S4S5	X	X	X			
<i>Dasiphora fruticosa</i> (L.) Rydberg		Shrubby Cinquefoil	G5T5	S5	X	X	X			X
<i>Deschampsia cespitosa</i> (L.) Palisot de Beauvois		Tufted Hairgrass	G5	S4S5	X	X	X			X

TABLE 1. (continued)

Species		Conservation status*					Alvar type			
Scientific name	Common name	Global	Subnational	Grassland	Shrubland	Savannah	Wetland			
<i>Drymocallis arguta</i> (Pursh) Rydberg	Tall Wood Beauty	G5	S5		X	X				
<i>Eleocharis</i> spp.	Spikerush species			X		X				X
<i>Elymus trachycaulus</i> subsp. <i>subsecundus</i> (Link) Á. Löve & D. Löve	One-sided Wildrye	G5	S5	X	X	X				
<i>Elymus trachycaulus</i> (Link) Gould ex Shinnars	Slender Wildrye	G5T5	S5	X						
<i>Erigeron philadelphicus</i> L.	Philadelphian Fleabane	G5	S5		X	X				
<i>Erigeron</i> spp.	Fleabane species				X	X				
<i>Festuca hallii</i> (Vasey) Piper	Plains Rough Fescue	G4	S3		X	X				
<i>Fragaria virginiana</i> Miller	Wild Strawberry	G5	S5		X	X				
<i>Gaillardia aristata</i> Pursh	Great Blanketflower	G5	S5		X	X				
<i>Galium boreale</i> L.	Northern Bedstraw	G5	S5	X	X	X				
<i>Geum triflorum</i> Pursh	Three-flowered Avens	G5	S4S5	X	X	X				
<i>Grindelia squarrosa</i> (Pursh) Dunal	Curly-cup Gumweed	G5	S5	X						
<i>Helianthus</i> sp.	Sunflower species				X	X				
<i>Helictochloa hookeri</i> (Scribner) Romero Zarco	Hooker's Oatgrass	G5	S3S4		X					
<i>Heuchera richardsonii</i> R. Brown	Richardson's Alumroot	G5	S5		X	X				
<i>Hieracium umbellatum</i> L.	Umbellate Hawkweed	G5	S5		X	X				
<i>Juncus dudleyi</i> Wiegand	Dudley's Rush	G5	S5	X						X
<i>Juniperus communis</i> L.	Common Juniper	G5	S5		X	X				
<i>Juniperus horizontalis</i> Moench	Creeping Juniper	G5	S5	X	X	X				X
<i>Koeleria macrantha</i> (Ledebour) Schultes	Prairie Junegrass	G5	S5	X	X	X				
<i>Lathyrus</i> sp.	Vetch species									
<i>Lepidium</i> sp.	Peppergrass species			X						
<i>Liatris ligulistylis</i> (A. Nelson) K. Schumann	Meadow Blazing-star	G5?	S4		X	X				
<i>Lilium philadelphicum</i> L.	Wood Lily	G5	S4		X	X				
<i>Linnaea borealis</i> L.	Twinflower	G5	S5		X	X				
<i>Linum lewisii</i> Pursh	Lewis' Wild Blue Flax	G5	S4		X	X				
<i>Lithospermum canescens</i> (Michaux) Lehmann	Hoary Puccoon	G5	S5	X	X	X				
<i>Lonicera dioica</i> L.	Limber Honeysuckle	G5	S5		X	X				
<i>Maianthemum canadense</i> Desfontaines	Wild Lily-of-the-valley	G5	S5		X	X				
<i>Maianthemum stellatum</i> (L.) Link	Starflower False Solomon's Seal	G5	S5		X	X				
<i>Medicago lupulina</i> (L.)	Black Medick	GNR	SNA		X	X				
<i>Melampyrum lineare</i> Desrousseaux	American Cow-wheat	G5	S3S5		X	X				
<i>Monarda fistulosa</i> (L.)	Wild Bergamot	G5	S5		X	X				
<i>Orthocarpus luteus</i> Nuttall	Yellow Owl's-clover	G5	S4S5		X	X				
<i>Oryzopsis asperifolia</i> Michaux	Rough-leaved Mountain Rice	G5	S5		X	X				
<i>Pedionelum esculentum</i> (Pursh) Rydberg	Large Indian Breadroot	G5	S3S4		X	X				
<i>Pellaea gastonyi</i> Windham	Gastony's Cliffbrake	G2G3	S1		X					
<i>Pellaea glabella</i> subsp. <i>occidentalis</i> (E.E. Nelson) Windham	Western Dwarf Cliffbrake	G5T4	S2		X					
<i>Phleum pratense</i> (L.)	Common Timothy	GNR	SNA	X	X					X
<i>Phlox hoodii</i> Richardson	Hood's Phlox	G5	S3		X	X				X

TABLE 1. (continued) Vascular plants, bryophytes, and lichens observed in each type of alvar.

Species			Conservation status*		Alvar type				
Scientific name	Common name		Global	Subnational	Grassland	Shrubland	Savannah	Wetland	
<i>Picea glauca</i> (Moench) Voss	White Spruce		G5	S5		X	X		
<i>Pinus banksiana</i> Lambert	Jack Pine		G5	S5		X	X		
<i>Poa annua</i> L.	Annual Bluegrass		GNR	SNA	X	X	X		
<i>Poa pratensis</i> L.	Kentucky Bluegrass		G5	S5	X	X	X		
<i>Poa</i> sp.	Bluegrass species					X	X		
<i>Polygala senega</i> L.	Seneca Snakeroot		G4G5	S4		X	X		
<i>Populus tremuloides</i> Michaux	Trembling Aspen		G5	S5		X	X		
<i>Potentilla anserina</i> (L.) subsp. <i>anserina</i>	Common Silverweed		G5	S5		X	X		
<i>Potentilla bipinnatifida</i> Douglas ex Hooker	Bipinnate Cinquefoil		G5	SU	X				
<i>Potentilla gracilis</i> Douglas ex Hooker	Slender Cinquefoil		G5	S4	X				
<i>Potentilla pennsylvanica</i> L.	Pennsylvania Cinquefoil		G5	SU	X	X			X
<i>Potentilla</i> sp.	Cinquefoil species				X				
<i>Prunus pennsylvanica</i> L. f.	Pin Cherry		G5	S5		X	X		
<i>Prunus virginiana</i> L.	Chokecherry		G5	S5		X			
<i>Quercus macrocarpa</i> Michaux	Bur Oak		G5	S5		X	X		
<i>Rhus glabra</i> L.	Smooth Sumac		G5	S3S4		X	X		
<i>Ribes oxycanthoides</i> L.	Canada Gooseberry		G5	S5		X	X		
<i>Rosa acicularis</i> Lindley	Prickly Rose		G5	S5	X	X	X		
<i>Rubus idaeus</i> L.	Red Raspberry		G5	S5		X	X		
<i>Rudbeckia hirta</i> L.	Black-eyed-Susan		G5	S5		X	X		
<i>Salix</i> spp.	Willow species					X	X		
<i>Sanicula marilandica</i> L.	Maryland Sanicle		G5	S5		X	X		
<i>Selaginella densa</i> Rydberg	Prairie Spikemoss		G5	S3		X			
<i>Shepherdia canadensis</i> (L.) Nuttall	Soapberry		G5	S5		X	X		
<i>Sisyrinchium montanum</i> Greene	Strict Blue-eyed-grass		G5	S5		X	X		
<i>Smilax lasioneura</i> Hooker	Hairy-nerved Carrionflower		G5	S4S5		X	X		
<i>Solidago hispida</i> Muhlenberg ex Willdenow	Hairy Goldenrod		G5	S5		X	X		
<i>Solidago missouriensis</i> Nuttall	Missouri Goldenrod		G5	S5		X	X		
<i>Solidago nemoralis</i> Aiton	Grey-stemmed Goldenrod		G5	S5		X	X		
<i>Solidago ptarmicoides</i> (Torrey & A. Gray) B. Boivin	Upland White Goldenrod		G5	S4S5		X	X		
<i>Solidago</i> spp.	Goldenrod species					X	X		
<i>Symphoricarpos</i> sp.	Snowberry species					X	X		
<i>Symphotrichum</i> spp.	Aster species				X	X	X		
<i>Symphotrichum ericoides</i> (L.) G.L. Nesom	White Heath Aster		G5	S4					
<i>Symphotrichum laeve</i> (L.) A. Löve & D. Löve	Smooth Aster		G5	S5	X	X	X		
<i>Taraxacum officinale</i> F.H. Wiggers	Common Dandelion		G5	SNA		X			
<i>Thalictrum venulosum</i> Trelease	Veiny Meadow-rue		G5	S5		X	X		
<i>Toxicodendron radicans</i> var. <i>rydbergii</i> (Small ex Rydberg) Erskine	Western Poison Ivy		G5	S5		X	X		
<i>Viburnum rafinesqueanum</i> Schultes	Downy Arrowwood		G5	S4S5		X	X		
<i>Vicia americana</i> Muhlenberg ex Willdenow	American Vetch		G5	S5		X	X		

TABLE 1. (continued)

Species		Conservation status*				Alvar type		
Scientific name	Common name	Global	Subnational	Grassland	Shrubland	Savannah	Wetland	
<i>Vicia</i> sp.	Vetch species			X	X		X	
<i>Viola</i> spp.	Violet species				X		X	
<i>Zizia aptera</i> (A. Gray) Fernald	Heart-leaved Alexanders	G5	S5		X		X	
<i>Zizia aurea</i> (L.) W.D.J. Koch	Golden Alexanders	G5	S4S5		X		X	
MOSSES								
<i>Abietinella abietina</i> (Hedw.) Fleisch.	Wiry Fern Moss	G4G5	S4S5	X	X		X	
<i>Aulacomnium palustre</i> (Hedw.) Schwaegr.	Ribbed Bog Moss	G5	S4S5		X		X	
<i>Barbula convoluta</i> Hedw.	Lesser Bird’s-claw Beard Moss	G5	SU	X	X		X	
<i>Brachythecium campestre</i> (C. Müll.) Schimp. in B.S.G	Field Ragged Moss	G4G5Q	SU		X		X	
<i>Brachythecium salebrosum</i> (Web. & Mohr) Schimp	Golden Ragged Moss	G5	S4S5		X		X	
<i>Brachythecium</i> sp.					X		X	
<i>Bryum</i> sp.				X	X		X	
<i>Campylium polygamum</i> (Schimp.in B.S.G) C. Jens.	Campylium Moss	G5	S4S5	X	X		X	
<i>Ceratodon purpureus</i> (Hedw.) Brid.	Red Roof Moss	G5	S4S5		X		X	
<i>Dicranum polysetum</i> Sw.	Wavy-leaf Broom Moss	G5	S4S5		X		X	
<i>Didymodon rigidulus</i> Hedw.	Rigid Beard Moss	G5	SU	X	X		X	
<i>Encalypta procera</i> Bruch	Slender Candlesnuffer Moss	G4G5	SU		X		X	
<i>Eurhynchium pulchellum</i> (Hedw.) Jenn.	Elegant Beaked Moss	G5	S4S5		X		X	
<i>Grimmia teretinervis</i> Limpr.	Round-nerved Grimmia	G3G5	SNR		X		X	
<i>Hedwigia ciliata</i> (Hedw.) P. Beauv.	Ciliate Hedwig’s Moss	G5	SU		X		X	
<i>Hylacomium splendens</i> (Hedw.) Schimp. in B.S.G	Stairstep Moss	G5	S4S5		X		X	
<i>Pleurozium schreberi</i> (Brid.) Mitt.	Red-stemmed Feather Moss	G5	S4S5		X		X	
<i>Ptychostomum pseudotriquetrum</i> (Hedw.) J.R. Spence & H.P. Ramsay	Tall Clustered Thread Moss	G5	S4S5	X	X		X	
<i>Sanionia uncinata</i> (Hedw.) Loeske	Sickle Moss	G5	S4S5		X		X	
<i>Syntrichia norvegica</i> Web.	Norway Screw Moss	G5	SU		X		X	
<i>Tortella fragilis</i> (Hook. & Wils. in Drumm.) Limpr.	Fragile Twisted Moss	G5	S4S5	X	X		X	
<i>Tortella tortuosa</i> (Hedw.) Limpr.	Frizzled Crisp Moss	G5	SU		X		X	
<i>Tortula ruralis</i> (Hedw.) Gaertn. <i>et al.</i>	Hairy Screw Moss	G5	S4S5	X	X		X	
LICHENS								
<i>Biatora vernalis</i> (L.) Fr.	Spring Dot Lichen	G5	S3S5		X			
<i>Mycobilimbia sabuletorum</i> (Schreb.) Hafellner	Six-celled Moss Dot Lichen	G5	S2S4		X			
<i>Caloplaca holocarpa</i> (Hoffm. ex Ach.) A. E. Wade	Firedot Lichen	G5	S3S5		X		X	
<i>Caloplaca jungermanniae</i> (Vahl) Th. Fr.	Jungermann’s Firedot Lichen	G4G5	S2S4		X			
<i>Cladina arbuscula</i> (Wallr.) Hale & Culb.	Reindeer Lichen	G5	S5		X		X	
<i>Cladonia botrytes</i> (K. G. Hagen) Willd.	Wooden Soldiers Lichen	G5	S4				X	
<i>Cladonia cariosa</i> (Ach.)	Split-peg Lichen	G5	S5		X			
<i>Cladonia cervicornis</i> ssp. <i>verticillata</i> (Hoffm.) Ahti	Ladder Lichen	G5T5	S4		X			
<i>Cladonia chlorophaea</i> (Flörke ex Sommerf.)	Mealy Pixie-cup Lichen	G5	S5		X			
<i>Cladonia cristatella</i> Tuck.	British Soldiers	G5	S5					X

TABLE 1. (continued) Vascular plants, bryophytes, and lichens observed in each type of alvar.

Species		Conservation status*				Alvar type		
Scientific name	Common name	Global	Subnational	Grassland	Shrubland	Savannah	Wetland	
<i>Cladonia macrophyllodes</i> Nyl.	Large-leaved Pixie Lichen	G4G5	SU		X			
<i>Cladonia multiformis</i> G. Merr.	Sieve Lichen	G5	S5		X			
<i>Cladonia pocillum</i> (Ach.) Grognot	Rosette Pixie-cup Lichen	G5	S4		X	X		
<i>Cladonia pyxidata</i> (L.) Hoffm.	Pebbled Pixie-cup	G5	S5		X			
<i>Cladonia ramulosa</i> (With.) J. R. Laundon	Branched Pixie-cup Lichen	G5?	SU			X		
<i>Cladonia symphycarpa</i> (Flörke) Fr.	Split-peg Lichen	G5	S4		X	X		
<i>Peltigera praetextata</i> (Flörke ex Sommerf.) Zopf	Scaly Pelt Lichen	G5	SU		X			
<i>Peltigera rufescens</i> (Weiss) Humb.	Felt Lichen	G5	S5		X	X		
<i>Physcia adscendens</i> (Fr.) H. Olivier	Hooded Rosette Lichen	G5	S5		X	X		
<i>Physcia aipolia</i> (Ehrh. ex Humb.) Fürnr.	Hoary Rosette Lichen	G5	SU		X	X		
<i>Physcia phaea</i> (Tuck.) J. W. Thomson	Black-eyed Rosette Lichen	G4G5	SU	X				
<i>Sarcogyne regularis</i> Körber	Frosted Grain-spored Lichen	G5	S3S5		X			
<i>Stereocaulon paschale</i> (L.) Hoffm.	Easter Foam Lichen	G5	SU		X			
<i>Verrucaria muralis</i> Ach.	Wart Lichen	G5	S2S4		X			
<i>Xanthoparmelia cumberlandia</i> (Gyelnik) Hale	Cumberland Rock-shield	G5	SU		X			
<i>Xanthoria polycarpa</i> (Hoffm.) Th. Fr. ex Rieber	Pincushion Sunburst Lichen	G5	S4		X	X		
LIVERWORTS								
<i>Cephaloziella rubella</i> (Nees) Warnst	Red Threadwort	G5	SU		X			X

*Global (NatureServe 2016) and subnational (Manitoba Conservation Data Centre unpubl. data) conservation status ranks.



FIGURE 3. Grazed grassland alvar at the Sylvan Alvar site. Photo: Nature Conservancy of Canada.



FIGURE 4. Shrubland alvar at the Clematis Alvar site. Photo: Nature Conservancy of Canada.



FIGURE 5. At the Clematis Alvar site, trees are often present along the periphery where the alvar transitions into woodland. Photo: Nature Conservancy of Canada.



FIGURE 6. Shrubland alvar at the Marble Ridge Alvar site. Some of the scattered boulders support Gastony's Cliffbrake (*Pellaea gastonyi*) or Western Dwarf Cliffbrake (*Pellaea glabella* ssp. *occidentalis*) or both. Photo: Nature Conservancy of Canada.

than in grassland alvars, although the abundance of each varies among sites. Sites vary from flat to having table-top limestone outcrops and scattered limestone boulders. Drainage is restricted at these sites, which are periodically flooded. In the absence of rain, drought-like conditions were observed.

Savannah alvars (Figures 7 and 8) are similar to shrubland alvars in their patchy distribution of vegetation. Soil depth is usually <5 cm, but frequently deeper in cracks and seams. Limestone pavement is frequent. Shrubs are dominant, followed by forbs, with graminoids less abundant. Unlike shrubland alvars, distribution of trees is regular, although still amounting to <60% cover, and tall shrubs can occur frequently. Bryophyte and lichen cover is variable and generally less dominant than in shrubland alvars. Like shrubland alvars, savannah alvars vary from being flat to having scattered boulders or table-top outcrops, but are more frequently associated with the latter than shrubland alvars. These sites flood periodically and exhibit drought-like conditions; however, extremes in moisture variability at sites with greater tree abundance are not as pronounced.

Like grassland alvars, wetland alvars have nearly continuous vegetative cover, with soils about 5 cm deep and occasional patches of exposed limestone pavement (Figure 9). They are dominated by wetland graminoids

and mosses, with few forbs or shrubs and no trees. These are low areas that grade into other alvar types. They are often partly bordered by willow-dominated swamps and marsh. Despite similar soil depths and cover as grassland alvars, these sites remain saturated enough to support wetland vegetation, but are not permanently flooded. It is unknown whether the difference is a result of increased water catchment from the surrounding topography or a difference in the degree of drainage restriction by the underlying bedrock.

Bedrock geology

Survey sites coincided with limestone bedrock from the Jurassic, Permian, Devonian, Silurian, and Ordovician geologic periods. Alvar was located only on Silurian and Ordovician bedrock, which consist primarily of dolomite (Manitoba Mineral Resources 2012a).

The Clematis Alvar and two units of the Poplarfield Alvar occur on Silurian bedrock, which consists of micritic, fossiliferous, stromatolitic, and biostromal dolomites, whereas the other alvars occur on Ordovician bedrock comprising various dolomites including argillaceous, nodular, and laminated dolomite (Manitoba Mineral Resources 2012a).

Alvars occur on four Ordovician formations. The Marble Ridge Alvar site and the rest of the Poplarfield Alvar sites are primarily located within the western



FIGURE 7. Savannah alvar with White Spruce (*Picea glauca*) at the Poplarfield Alvar site. Photo: Nature Conservancy of Canada.



FIGURE 8. Savannah alvar with Jack Pine (*Pinus banksiana*) at the Marble Ridge Alvar site. Photo: Nature Conservancy of Canada.



FIGURE 9. Wetland alvar at the Marble Ridge Alvar site. Photo: Nature Conservancy of Canada.

Stony Mountain Formation and the East Arm Formation, whereas the Peguis and Sylvan Alvars fall into the eastern Stony Mountain Formation and the Red River Formation (Manitoba Mineral Resources 2012a).

Significant species

Twenty-four globally, nationally, or provincially rare and uncommon species (NatureServe 2016; Manitoba Conservation Data Centre unpubl. data) were documented at survey sites during this study or previously by Caners (2011). Globally uncommon and provincially endangered Gastony's Cliffbrake (*Pellaea gastonyi* Windham; Friesen and Murray 2015) and globally uncommon Grimmia Dry Rock Moss (*Grimmia teretivervis* Limpricht; Caners 2011) were observed growing on limestone cliffs and boulders at the Marble Ridge Alvar sites. Vascular plant species assessed as provincially uncommon or rare (Manitoba Conservation Data Centre unpubl. data) observed during this study include: Dwarf Western Cliffbrake (*Pellaea glabella* ssp. *occidentalis* (E.E. Nelson) Windham), Rough Fescue (*Festuca hallii* (Vasey) Piper), Porter's Chess (*Bromus porteri* (J.M. Coulter) Nash), Wild White Onion (*Allium textile* A. Nelson & J.F. Macbride), Spring Birch (*Betula occidentalis* Hooker), Spike-oat (*Avenula hookeri* (Scribner) Holub), American Cow-wheat (*Melampyrum lineare* Desrousseaux), Large Indian Breadroot (*Pedimelum esculentum* (Pursh) Rydberg), Smooth Sumac (*Rhus glabra* L.), and Dense Spikemoss (*Selaginella densa* Rydberg; Table 1). Six species of lichens observed during this study and six species of bryophytes documented by Caners (2011) are also assessed as nationally or provincially rare or uncommon (NatureServe 2016; Manitoba Conservation Data Centre unpubl. data).

Six non-native plant species were observed in alvars. Timothy (*Phleum pratense* L.) was observed often, but never as a dominant species. Kentucky Bluegrass (*Poa pratensis* L.) was observed in some grass-dominated alvars. Annual Bluegrass (*Poa annua* L.) was observed in some alvars, often occurring on sparsely vegetated patches of shallow, bare soil. Garden Bird's-foot Trefoil (*Lotus corniculatus* L.) was found on the periphery of two alvars and, at a third site, there were a few scattered plants on the alvar itself. Awnless Brome (*Bromus inermis* Leysser) and Creeping Bentgrass (*Agrostis stolonifera* L.) were each observed once in a grazed alvar.

Overall, it appears that non-native species in Manitoba alvars are infrequent, and invasive species that are of high priority for detection and control in Manitoba (Invasive Species Council of Manitoba 2018) are not currently present in these ecosystems. Non-native or invasive plant species can result in reduced biodiversity and function in natural ecosystems and are becoming increasingly widespread in open habitats in the prairie provinces (Canadian Food Inspection Agency 2008; Sinkins and Otfinowski 2012; DeKeyser et al. 2013). The relatively limited presence of non-native or inva-

sive species in Manitoba alvars represents a rare opportunity to prevent further establishment and maintain the exceptional biodiversity of these habitats.

Management and conservation context

Alvars make up 0.3% (3934 ha) of the south Interlake. Each alvar type supports its own complement of plants and contributes uniquely to the biological diversity of Manitoba. The significance of alvar habitat and the threats it faces across Canada have been extensively documented (Catling and Brownell 1995, 1999b; Reschke et al. 1999; Catling 2014; Catling et al. 2014; Brunton and Catling 2017). Protection and conservation efforts in Manitoba should initially focus on preserving representatives of each type. In addition to supporting vascular plant species assemblages distinct from other ecosystems in Manitoba, different types of alvar support a range of other species groups. For example, we observed grassland-obligate birds, a group undergoing steep population declines in North America (North American Bird Conservation Initiative 2016), on grassland alvars; Eastern Whip-poor-will (*Antrostomus vociferus*) and Common Nighthawk (*Chordeiles minor*), both threatened species (SARA Registry 2018a,b), have been documented in shrubland and savannah alvars with sparse vegetation (Manitoba Conservation Data Centre unpubl. data). Alvars associated with inland cliffs, outcrops, and boulders, such as along Marble Ridge, provide a wide range of microhabitats not found in other alvar types, and support a number of bryophytes that are expected to remain uncommon in the region (Caners 2011).

Approximately one third (1261 ha) of alvar in Manitoba occurs on privately owned land, with the remainder on public land including wildlife management areas, community pastures, and undesignated provincial Crown land.

No alvar sites identified in this study are located within the boundaries of protected areas (IUCN Protected Areas Classification level IV or higher; Manitoba Conservation and Water Stewardship 2012b) or are protected from all types of development. A 2560-ha ecosystem protection zone that encompasses most of the Marble Ridge Alvar site has been proposed.

Approximately 12% of the Manitoba alvar habitat identified in this study falls under mining and/or quarry leases (Manitoba Mineral Resources 2012b) and, thus, may be exposed to habitat destruction from mining activities. At the time of our survey, near-surface limestone had been commercially extracted immediately adjacent to or within alvar communities at six locations.

Approximately 76% (2985 ha) of alvar habitat identified in this study was being grazed at the time of the survey or exhibited signs of having been grazed recently. Another 11% (432 ha) did not appear to be grazed by domestic livestock. Most observed grazing animals were cattle, but horses and bison were also observed. Land use at the other locations (13%) could not be determined. Pre-European settlement grazing histories for

the Interlake area are unclear (Henderson and Koper 2014), but grazing by large ungulates has likely always contributed to the disturbance regime of Manitoba alvars and may play an important role in maintaining their openness, as it does in alvars elsewhere (Reschke *et al.* 1999). However, current grazing management using livestock is unlikely to mirror historical patterns (Henderson and Koper 2014), and grazing at incompatible frequencies, intensities, or durations may result in alterations to species composition and facilitate the spread of non-native species (Reschke *et al.* 1999).

No evidence of recent natural fire, an important ecological requirement of many alvar habitats (Catling and Brownell 1998; Catling *et al.* 2002; Jones and Reschke 2005; Catling 2009b), was observed in or near any of the alvars. Trembling Aspen (*Populus tremuloides* Michaux) encroachment was observed at some locations in the Clematis Alvar and Poplarfield Alvar sites. Long-term fire suppression is probably negatively impacting the ecological integrity and biodiversity of alvar habitat here, as it is in other open habitats in southern Manitoba (e.g., Koper *et al.* 2010) and throughout North America.

The current mix of public and private land ownership, history of fire suppression, and the economic potential of alvars for grazing and mineral resources highlight the need for the involvement and cooperation of a range of stakeholders, including industry and private landowners, in alvar conservation.

Further research

This study presents only a first approximation of the various types of alvar present in Manitoba, and there is a need for classification of alvar habitat in the province using a quantitative data-based scheme. This would help to refine the conservation status of alvar types/subtypes and to inform site-condition metrics, compatible land-management activities, and conservation opportunities. Faunal surveys to further assess the biodiversity of these sites are also needed. The selection of appropriate conservation management options in Manitoba requires full investigation of the relation between the ecological integrity of alvar habitat and ecological processes, such as grazing and fire suppression.

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Abstract

New breeding records for 10 species of tundra and boreal nesting birds were documented near the community of Kugluktuk (Nunavut, Canada) over the course of the 2015 and 2016 breeding seasons and incidentally in 2017 and 2018. These species include American Wigeon (*Mareca americana*), Mallard (*Anas platyrhynchos*), Northern Shoveler (*Anas chlypeata*), Green-winged Teal (*Anas carolinensis*), Greater Scaup (*Aythya marila*), Say's Phoebe (*Sayornis saya*), Canada Jay (*Perisoreus canadensis*), Grey-cheeked Thrush (*Catharus minimus*), Yellow-rumped Warbler (*Setophaga coronata*), and Dark-eyed Junco (*Junco hyemalis*). Previously unpublished breeding evidence for Bald Eagle (*Haliaeetus leucocephalus*) is also discussed along with suspected breeding of Barn Swallow (*Hirundo rustica*), Bohemian Waxwing (*Bombycilla garrulus*), White-throated Sparrow (*Zonotrichia albicollis*), and Pine Grosbeak (*Pinicola enucleator*). These records represent the first described breeding occurrences for these species in the Kitikmeot region, or new records for the mainland of Nunavut. A lack of historical ornithological survey effort in this area has likely led to the diversity of these previously unrecorded breeding observations. These results highlight the need to increase geographic coverage of bird surveys in northern Canada to more accurately delineate the northern limit of breeding ranges and suggest that further formal survey effort will undoubtedly lead to additional new breeding records.

Key words: Breeding records; range extensions; Arctic; Nunavut; Kugluktuk

Introduction

Located in the westernmost portion of Nunavut, Kugluktuk boasts some of the greatest diversity of terrestrial flora (Saarela *et al.* 2017) and fauna in the territory (Lamont and Knaggs 2016; eBird 2017). The region is also well known for harbouring robust populations of diurnal birds of prey, observed during surveys in the 1980s and 1990s before the establishment of Nunavut (Bromley and McLean 1986; Shank *et al.* 1990) and confirmed through more recent raptor surveys (Lamont *et al.* 2016, 2018).

Until recently, little ornithological survey activity has occurred near the hamlet of Kugluktuk. Previous surveys in the mid-2000s were made from rotary and fixed-wing aircraft and targetted mainly breeding waterfowl (Conant *et al.* 2007; Groves and Mallek 2011) or nesting raptors (Bromley 1982; Bromley and McClean 1986; Shank 1996; Lamont *et al.* 2016). Such methods lack the precision needed to detect young or nests, particularly of Passeriformes. In spring 2017, the first set of the Arctic Program for Regional and International Shorebird Monitoring (PRISM) surveys was undertaken around Kugluktuk by the Canadian Wildlife Service (J. Rausch pers. comm. 6 June 2017).

This overall lack of survey effort, compared with other parts of the territory, which have seen years or decades of ornithological research and amateur birding (e.g., Bylot Island, Cambridge Bay, Coats Island), has resulted in a potential gap in our understanding of the true breeding range of some avian species in the western Kitikmeot. The proximity of the treeline to Kugluktuk, in addition to the northward flow and funnelling valleys of the Coppermine, Richardson, and Rae Rivers, all contribute to the presence of species in the region that are

normally only found at much lower latitudes elsewhere in the territory. Summarized herein are observations of detected nests and recently fledged young for 10 species of birds, previously lacking breeding evidence for the territory or for the Kitikmeot region. I follow the recent examples of Hussell *et al.* (2012) and Lecomte and Giroux (2015), who highlight the importance of documenting and reporting new breeding records in Nunavut to help expand our knowledge of avian distributions in the Canadian Arctic and to potentially aid in detecting changes in bird communities at given locations over time.

Methods

Kugluktuk is located in the western Kitikmeot region of Nunavut, at the mouth of the Coppermine River (67.81°N, 115.09°W; Figure 1). This area is within the Southern Arctic Terrestrial Ecozone (Wilken 1986): mean annual temperature is –11°C, mean summer temperature 5°C, and mean winter temperature –26°C, average annual precipitation 200 mm (northern part of the region) to 300 mm (southern portions). A nearly continuous cover of shrub tundra vegetation exists, consisting of Alaska Willow (*Salix alaxensis* (Andersson) Coville var. *alaxensis*), Arctic Willow (*Salix arctica* Pallas), Dwarf Birch (*Betula glandulosa* Michaux), Alpine Bearberry (*Arctostaphylos alpina* (L.) Niedenzu), Dwarf Labrador Tea (*Rhododendron tomentosum* subsp. *decumbens* (Aiton) Elven & D. F. Murray), and *Dryas* spp. and sedge (*Carex* spp.) tussocks (Wilken 1986). The proximity to the treeline and the more temperate microclimates associated with the Coppermine, Rae, and Richardson River valleys, provide shelter from harsh Arctic winds for a variety of plant species.

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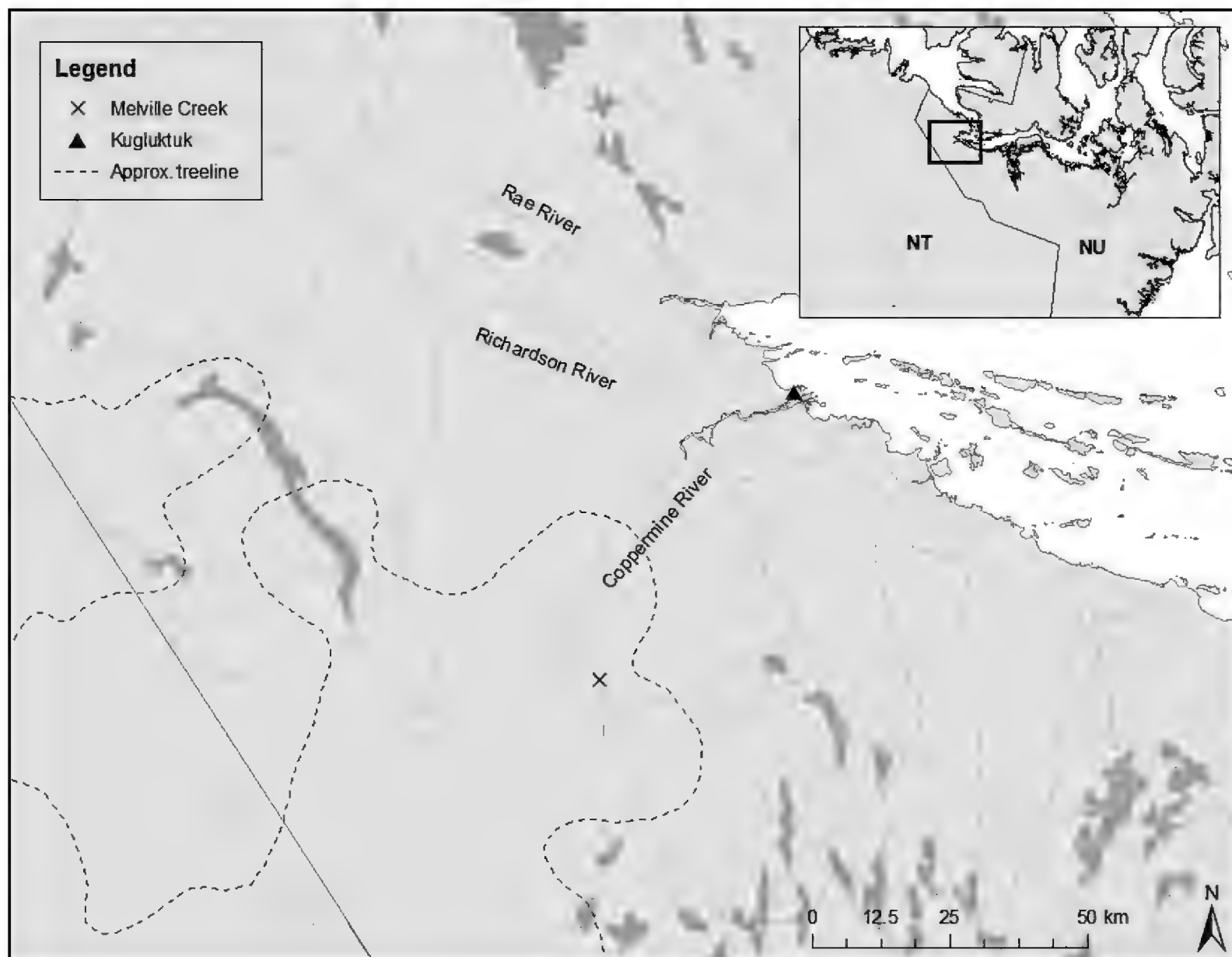


FIGURE 1. Location of the study area, Kugluktuk, Nunavut depicting the Rae, Richardson and Coppermine Rivers and the location of Melville Creek, south of Kugluktuk.

I conducted localized, visual, ground surveys within a 20-km radius (unless otherwise noted) of Kugluktuk. Incidental observations and surveys were undertaken throughout the year, from 1 January 2015 through 31 August 2016 while I was living in the hamlet, with an additional week of observations in July 2017 and one week in June and July 2018, respectively. All ground observations were made on the west side of the Coppermine River. Ground surveys were undertaken systematically following Arctic PRISM protocols (Bart and Johnson 2012), through targeted habitat surveys and opportunistic encounters. Nests and/or recently fledged young were documented to confirm breeding activity.

Results and Discussion

AMERICAN WIGEON (*Mareca americana*)

During the 2015–2016 field seasons, this species was observed feeding in local wetlands, ephemeral pools, and ponds around Kugluktuk, often with other species of waterfowl such as Northern Pintail (*Anas acuta*) and Mallard (*Anas platyrhynchos*). On 13 July 2016, a female was flushed from a small pond, accompanied by nine ducklings of age subclass Ia (Figure S1).

American Wigeon is known to favour taiga environments and is often found in the transition zone between

boreal and tundra ecozones (Silver *et al.* 2012; Mini *et al.* 2014) and on Akimiski Island (K. Abraham pers. comm. 21 August 2016); however, despite these habitat preferences, relatively few records exist for Nunavut. The first documented breeding evidence was recorded by Harper (1953) near Windy River (south Kivalliq); one other observation of recently fledged young occurred in Bathurst Inlet in 1996 (eBird 2017). The breeding record described here is believed to be only the second and northernmost breeding evidence for the territory.

MALLARD (*Anas platyrhynchos*)

In 2015, several pairs of Mallards were observed in the vicinity of Kugluktuk, occupying small ponds and foraging in ephemeral pools. Pursuit flights were often observed during the spring months. On 13 July 2016, a female was flushed from the edge of a small pond with two young, approximately age subclass Ib (Figure S2).

Although Mallard has a wide distribution and is considered a habitat generalist (Drilling *et al.* 2018), only sporadic observations of this species exist north of the treeline (eBird 2017). The only previous confirmed breeding records in Nunavut are from James Bay on Stag Rock, where a nest with ten eggs was found on 26 June 1995 (Tymstra 1997) and near Windy River, where young and nests have been observed (Harper 1953). The

record described here is believed to be the westernmost and northernmost breeding evidence for the territory and the first for the Kitikmeot region.

NORTHERN SHOVELER (*Anas clypeata*)

Sightings of this species occurred regularly throughout the 2015–2016 seasons. On 18 May 2015, six males and five females were observed, followed by two pairs on 31 May, and eight males and only one female on 21 June. On 24 June, a female was flushed from a nest. The clutch consisted of nine eggs and was located in a small, wet sedge meadow approximately 20 m from a small pond (Figure S3). Several pairs were again seen in 2016, although no nesting was confirmed.

Few observations of this species exist in northern Canada (J. Richards pers. comm. 23 August 2016; eBird 2017). It is present throughout the coast of James Bay in Ontario and on the west side of Hudson's Bay (Ross and North 1983; eBird 2017); however, there are no nesting records for Nunavut except one on Akimiski Island from 21 May 2001 (K. Abraham pers. comm. 19 March 2016). Several pairs have recently been observed in Cambridge Bay (S. Menu pers. comm. 10 June 2016; eBird 2017). The breeding record described here is believed to be the first for mainland Nunavut and the northernmost breeding evidence for the territory.

GREEN-WINGED TEAL (*Anas carolinensis*)

Regularly seen in both 2015 and 2016, with more males than females observed in both years, this species made extensive use of small ponds and ephemeral pools for breeding, feeding, moulting, and rearing young. In 2015, pursuit flights and courtship were observed with breeding suspected. On 13 July 2016, a young duckling of age subclass Ia was seen feeding on the surface of a pond and the female later flushed (Figure S4). Two flightless males in mid-moult were also flushed from the same area. On 20 July 2016, a second brood of eight young of age subclass Ib was encountered in the same location.

Although this species is usually associated with boreal ecosystems (Johnson 1995), a surprising number of records exist above the treeline in Nunavut, but most lack breeding evidence (eBird 2017). A female with 10 young was observed on Carey Island, James Bay, on 21 June 1995 (Tymstra 1997), and Harper (1953) describes records of young birds near Simon's Lake in the southern Kivalliq region. Beyond these two records, little evidence has been formally described in the literature for Nunavut. The breeding record described here is believed to be the westernmost and northernmost breeding evidence for the territory and the first for the Kitikmeot region.

GREATER SCAUP (*Aythya marila*)

Numerous pairs of this species were observed in both 2015 and 2016. Multiple pairs were observed feeding in shallow ponds or pools, some ephemeral. In 2015, courtship behaviours were observed, but no nests or fledged young were found. On 13 July 2016, a female was flushed from a nest (Figure S5) in a sedge meadow,

in close proximity to where courtship was detected the previous year. The clutch consisted of eight eggs and appeared to be in a late stage of incubation based on the size of the air cell. On 26 July 2016, 12 males and three females with 28 ducklings were observed on a large pond 10 km west of Kugluktuk. Broods were all approximately the same age and appeared to be of subclass Ib.

Mainly restricted to coastal tundra from Alaska east to Hudson's Bay and the Nunavik region (Kessel *et al.* 2002), this species has been found in low densities from Kugluktuk to Cambridge Bay, through the Queen Maud Gulf and in inland areas of the southern Kivalliq region (Conant *et al.* 2007; Groves and Mallek. 2011; eBird 2017). Harper (1953) describes the species as breeding in southern Kivalliq, but suggests that they do not extend appreciably into the barren grounds. The record described here is believed to be the westernmost and northernmost breeding evidence for the territory and the first for the Kitikmeot region.

SAY'S PHOEBE (*Sayornis saya*)

On 24 May 2016, one male was observed within the town limits of Kugluktuk. The bird responded aggressively to recorded calls of conspecifics. On 28 May 2016, two birds were seen near a large cliff face 100 m south of the initial observation. On 19 June, only one bird was observed, feeding and returning to a large cracked rock slab that created a small crevice about 20 m up the cliff wall. The bird would continually feed and return to this location, occasionally entering the structure and returning into view several minutes later. On 21 July 2016, both adults were observed carrying food to the same location and presumably feeding a chick. On 26 July 2016, a second breeding pair was observed carrying food, and a young bird was heard begging along a cliff face, approximately 1 km south of the previous site. A nest was soon detected under a rock overhang about 2 m above the ground (Figure S6) with two infertile eggs still present. A single fledged young was observed, nearly adult size, and capable of extended flight. This same nest location was visited exactly one year later and found to have been active that season with one infertile egg still present. The same site was visited again in June and July 2018 and was active.

The timing of arrival of this species in Kugluktuk is consistent with what is known for male and female arrival on territories (Dawson 1923; Johnsgard 1979) despite its northern latitude. Both observed nesting sites were typical of what has been described for the species (Bent 1942; Schukman *et al.* 1976). It is worth noting that the abandoned nest discovered with two infertile eggs in 2016 was removed for photographic and archival purposes and was rebuilt in exactly the same fashion and location, with nearly identical nesting materials and re-occupied, presumably, by this same pair in the 2017 season. This same process of nest removal and archiving was repeated in 2017 after the nest was abandoned, and re-made and reused in 2018 as it was the previous year. Of interest were two observations of territorial birds re-

sponding to playback during a raptor survey in July 2017: one record 70 km west of Kugluktuk and another 30 km east of Kugluktuk. It is likely that additional surveys in the Kitikmeot, particularly on rock bluffs with a southern aspect, would result in a number of additional breeding records.

Only one previous breeding record for Nunavut exists, this being a photographed nest site on a shed on Nauyak Lake on Kent Peninsula on 28 June 2008 (J. Richards pers. comm. 11 June 2016; eBird 2017). The records described here are believed to be the westernmost confirmed breeding evidence for the territory.

CANADA JAY (*Perisoreus canadensis*)

A pair and two juveniles were seen and photographed on 24 July 2018 (Figure S7) near the confluence of Melville Creek and the Coppermine River ~60 km south of the Kugluktuk. Multiple birds were heard calling. The species has apparently been established along the tree-line for many years (A. Niptanatiak pers. comm. 25 July 2018) and has likely gone unnoticed by ornithologists due to a lack of survey effort. Habitat was dominated by Black Spruce (*Picea mariana* (Miller) Britton, Sterns & Poggenburgh), including relatively large specimens, upwards of 50 cm in diameter and 10 m tall, with an understorey of waist high Dwarf Birch, *Salix* sp., Shrubby Cinquefoil (*Dasiphora fruticosa* (L.) Rydberg), and a carpet of moss. The ecology was very similar to boreal forest found further south, with the sheltered river valley providing refugia for this habitat to proliferate. The records described here are believed to be the northernmost confirmed breeding evidence for the territory (Richards and Gaston 2018).

GRAY-CHEEKED THRUSH (*Catharus minimus*)

I observed a recently fledged juvenile on 24 July 2018 (Figure S8) near the confluence of Melville Creek and the Coppermine River ~60 km south of Kugluktuk. The chick still had downy feathers on his crown and nape. Multiple birds were heard calling prior to the sighting. Habitat conditions were similar to those described for Canada Jay. The records described here are believed to be the northernmost breeding evidence for the territory (Richards and Gaston 2018).

YELLOW-RUMPED WARBLER (*Setophaga coronata*)

I observed a pair of birds in a willow thicket within the hamlet limits on 8 June and again on 20 June 2015, followed by observations of a singing male over the course of June and July 2015. In 2016, only a single male was observed, but it was seen singing from the second week of June until the end of the month in the same location as the previous year. On 23 July 2016, a male was seen carrying food in Kugluk/Bloody Falls Territorial Park, about 13 km south of Kugluktuk. The male was observed feeding a recently fledged young (Figure S9). On 19 July 2017, a male was seen feeding a fledged young capable of sustained flight within the hamlet limits of Kugluktuk. On 24 July 2017, another

male was seen feeding a recently fledged young 30 km northeast of Kugluktuk.

Kugluktuk is the only community in Nunavut with consistent sightings of this species since at least 2003 (eBird 2017); all are believed to be of the Myrtle group, *Setophaga coronata hooveri*. Previous recordings are known from the James Bay area, including Akimiski and smaller islands (Tymstra 1996, 1997), as well as in the Nueltin Lake area (Harper 1953; Mowat and Lawrie 1955). The first eBird records for Kugluktuk are of two birds (sexes not mentioned) on 11 June 2003, a single bird on 28 June 2013, and three birds (sexes not mentioned) in the adjacent Richardson River Valley on 13 August 2010. The records described here are believed to be the first confirmed breeding evidence for Nunavut.

DARK-EYED JUNCO (*Junco hyemalis*)

I observed an adult carrying food and subsequently feeding a recently fledged juvenile on 24 July 2018 at the confluence of Melville Creek and the Coppermine River (Figure S10). Habitat conditions were similar as those described for Canada Jay. The record described here is believed to be the northernmost confirmed breeding evidence for the territory.

BARN SWALLOW (*Hirundo rustica*)

A pair was observed in Kugluktuk for two consecutive breeding seasons, on 30 May 2015 and 13 June 2016. On 19 July 2015, a pair was observed near an unoccupied building within the hamlet limits. The pair began alarm calling as I approached and was later seen carrying insects. On 19 June 2016, a pair was seen collecting mud within the hamlet limits. No observations were made of this species in 2017–2018; however, survey effort was minimal compared with 2015 and 2016.

Many Barn Swallows have been seen in the Canadian Arctic (eBird 2017), but only one confirmed nesting exists for Nunavut: on a tower on Akimiski Island in July 1999 (K. Abraham unpubl. data). Late nest construction was observed in Arviat on 6 August 2008 (Eckert 2009) and a pair was seen in Rankin Inlet in 2016 (eBird 2017), but otherwise no confirmed nesting has been reported on the mainland portion of the territory. Further study in the Kugluktuk area may lead to eventual nesting detection. The records described here are believed to be the northernmost evidence for suspected breeding in the territory.

BOHEMIAN WAXWING (*Bombycilla garrulus*)

I observed what is believed to have been a pair within the hamlet limits of Kugluktuk on 23 June 2018 (Figure S11). They were feeding on Black Crowberry (*Empetrum nigrum* L.) from the previous season. Playback calls were made which generated minor response. It is likely that these birds overshot their migration past the treeline ~40 km south which would have provided suitable breeding habitat. An earlier observation from Kugluktuk was made between 19 July to 6 August 1989, however this was a single bird (Richards and Gaston 2018). This is believed to be the northernmost record

of a pair in suitable habitat for the territory and breeding in this region is highly suspected.

WHITE-THROATED SPARROW (*Zonotrichia albicollis*)

I documented multiple singing males of this species on 24 July 2018 near the confluence of Melville Creek and the Coppermine River. Habitat conditions were similar to those described for Canada Jay. Calling males were in suitable habitat and breeding was highly likely. A male specimen from Kugluktuk (Richards and Gaston 2018) was collected by F.W. Schueler in 1975. This area likely represents the northernmost extent of potential breeding for the territory.

PINE GROSBEAK (*Pinicola enucleator*)

I documented a singing male on 24 July 2018 (Figure S12) near the confluence of Melville Creek and the Coppermine River. Habitat conditions were similar to those described for Canada Jay. The bird was in suitable habitat and appeared to be moulting. The record described here is believed to be the northernmost evidence for suspected breeding in the territory.

BALD EAGLE (*Haliaeetus leucocephalus*)

Two adult Bald Eagles, believed to be a pair based on courtship pursuit flights, were documented near the mouth of the Coppermine River and in Kugluk/Bloody Falls Territorial Park for the 2015–2016 breeding seasons. Territorial chasing between these two birds and a resident breeding pair of Golden Eagles (*Aquila chrysaetos*) was observed on multiple occasions, although no nests of Bald Eagles were located. Additional observations of both adult and sub-adult Bald Eagles were made in late July 2017 in both Kugluk/Bloody Falls Territorial Park and near the mouth of the Rae River.

A review of unpublished data from the jointly managed Government of Northwest Territories and Nunavut/NWT Raptor Database (2017) revealed a single record of a Bald Eagle sitting on a nest approximately 3 km southeast of Bloody Falls on 8 May 1993. In 2017, the same site was found to be an occupied Golden Eagle territory. Local ecological knowledge suggests that this species has been regularly occupying this region for nearly a decade and an experienced local resident has suggested that a pair's nest was removed during deactivation of a Distant Early Warning radar tower at Cape Young (Pin-2, 68.935°N, 116.936°W) in the mid 2000s, 150 km northwest of Kugluktuk (A. Niptanatiak pers. comm. 20 July 2018). Over the last several years, irruptive behaviours have been documented for this species in the Queen Maud Gulf (K. Drake pers. comm. 15 August 2016), and further surveys in this area will likely result in additional breeding records. The previously unpublished record from 1993 represents what is believed to be the first breeding record for the territory.

Conclusion

Whether breeding of the described species in the western Kitikmeot has occurred relatively recently as a result of climatic shifts or has simply been undetected

because of a paucity of surveys remains unknown. Avian species ranges are known to be highly dynamic and subject to influence from both climatic and local environmental factors (Parmesan 2006; Virkkala *et al.* 2008, 2010, 2014). The proximity of Kugluktuk and the western Kitikmeot to the boreal–taiga transition zone means that this region likely falls within the northern range limit for a number of both bird and mammal species. This location is also known to harbour vagrants, such as Townsend's Solitaire (*Myadestes townsendi*; Lamont and Knaggs 2016), and previous suspected breeding of this species was confirmed in 2017 near Behchoko, approximately 50 km northwest of Yellowknife (L. McLeod pers. comm. 6 July 2017).

Similarly, the vascular plant biodiversity is among the richest in Nunavut, with 14 taxa in Kugluk/Bloody Falls Territorial Park not found elsewhere in the territory (Saarela *et al.* 2017). Beyond aerial surveys for raptors and waterfowl (Bromley and McLean 1986; Shank 1996; Conant *et al.* 2007; Lamont *et al.* 2016, 2018), possibly no formal efforts have been made to document passerine diversity. Given that my observations were all collected in a highly localized area, with most travel on foot, more intensive surveys would likely yield additional species previously unrecorded for the region or, potentially, the territory. Those conducting surveys in Nunavut should submit their observations to eBird (www.ebird.com) as recommended by Environment and Climate Change Canada to help define breeding ranges or species previously unknown to breed in the territory.

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SUPPLEMENTARY MATERIAL:

FIGURE S1. Female American Wigeon (*Anas americana*) with young brood on a small pond near Kugluktuk.

FIGURE S2. Female Mallard (*Anas platyrhynchos*) with duckling at edge of small pond near Kugluktuk.

FIGURE S3. Northern Shoveler (*Anas clypeata*) nest found in a sedge meadow near Kugluktuk.

FIGURE S4. Green-wing Teal (*Anas carolinensis*) duckling near Kugluktuk.

FIGURE S5. Greater Scaup (*Aythya marila*) nest in a sedge meadow near Kugluktuk.

FIGURE S6. Say's Phoebe (*Sayornis saya*) nest under rock overhang near Kugluktuk.

FIGURE S7. Juvenile Canada Jay (*Perisoreus canadensis*) near Melville Creek south of Kugluktuk.

FIGURE S8. Recently fledged Grey-cheeked Thrush (*Catharus minimus*) near Melville Creek, south of Kugluktuk.

FIGURE S9. Male Yellow-rumped Warbler (*Setophaga coronata*) with recently fledged juvenile, Kugluk/Bloody Falls Territorial Park south of Kugluktuk

FIGURE S10. Dark-eyed Junco (*Junco hyemalis*) carrying insects near Melville Creek, south of Kugluktuk.

FIGURE S11. Bohemian Waxwing (*Junco hyemalis*) seen within the hamlet of Kugluktuk in June 2018.

FIGURE S12. A male Pine Grosbeak (*Pinicola enucleator*) singing near Melville Creek, south of Kugluktuk.

First record of Commander Skate (*Bathyraja lindbergi*) in Canadian Pacific waters

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Abstract

We report the first verified record of a Commander Skate (*Bathyraja lindbergi* Ishiyama and Ishihara, 1977) from British Columbia, Canada. A female measuring 829 mm in total length was captured by bottom trawl on 2 August 2009 in Queen Charlotte Sound, Canada (51°37'N, 130°6'W). The depth of capture was 449 m. We used physical characteristics as well as meristic and morphometric characters to identify the specimen as a Commander Skate.

Key words: Commander Skate; *Bathyraja lindbergi*; British Columbia; first record; range extension

Commander Skate (*Bathyraja lindbergi* Ishiyama and Ishihara, 1977) was described based on several specimens captured in the Bering Sea at depths between 160 m and 570 m. The species is found throughout the Bering Sea southward from approximately 60°N (Ishiyama and Ishihara 1977; Mecklenburg *et al.* 2002); in the eastern North Pacific throughout the Aleutian Islands and in the Gulf of Alaska as far south as the Alexander Archipelago (Stevenson *et al.* 2007); and in the western North Pacific along the Kamchatka Peninsula (Ishiyama and Ishihara 1977) into the Sea of Okhotsk near Hokkaido (Masuda *et al.* 1984). It is found in waters ranging in depth from 126 m to 1193 m (Stevenson *et al.* 2007), but usually deeper than 200 m (Mecklenburg *et al.* 2002). A record reported at a depth of 2000 m is based on an erroneous species identification (Mecklenburg *et al.* 2002). Because of its deep-water habitat, Commander Skate is encountered infrequently in commercial fisheries; for example, from 2004 to 2008, only 100 kg of Commander Skate were recorded by observers as annual bycatch in United States Gulf of Alaska groundfish fisheries (Stevenson and Lewis 2010).

Commander Skate, like all members of the softnose skate family Arhynchobatidae and especially the genus *Bathyraja*, has a soft, flexible snout. In addition, Commander Skate has a short, broad snout and is differentiated from other sympatric species of *Bathyraja* by the absence of scapular thorns and the presence of a continuous row of well-developed, mid-dorsal thorns from the scapular region to the first dorsal fin (Ishiyama and Ishihara 1977).

On 2 August 2009, a Commander Skate was captured by bottom trawl during a research survey conducted on the *M.V. Viking Storm* in Canadian Pacific waters at 51°37'N, 130°6'W. The modal depth of the fishing event was 449 m. The specimen (Figure 1) was a female with a total length of 829 mm, a size at about which 50% of females are mature (Ebert 2005). Initial species iden-

tification was based on Stevenson *et al.* (2007), namely: flexible and short snout; scapular thorns absent; median tail thorns well developed along entire length of tail; dorsal surface grey-brown in colour, with ventral surface grey and darker around pectoral and pelvic fin margins; white colour around mouth and nostrils; ventral surface of disc smooth and without denticles; mid-dorsal thorns present and strong. Some authors consider the closely related species *Bathyraja matsubarai* to be a synonym for Commander Skate (Mecklenburg *et al.* 2002), which has contributed to confusion regarding this species' depth range and geographic distribution. *Bathyraja matsubarai* is dark purplish brown in colour and has an interrupted row of mid-dorsal thorns (Ishiyama and Ishihara 1977); neither characteristic applies to our specimen.

The specimen was frozen at sea and thawed later in the laboratory for character counts and measurements according to Hubbs and Ishiyama (1968) and Ishiyama and Ishihara (1977; Table 1). A muscle tissue sample was preserved in 95% undenatured ethanol for genetic analyses. The whole specimen was transferred to the Royal British Columbia Museum (Victoria, British Columbia, Canada) ichthyology collection for long-term storage (catalog number: RBCM 16401). As such, character measurements that required dissection (i.e., spiral valves of the intestine, eyeball length, length of electric organ, and cranium size) were not made. Radiographs were used for vertebral counts, but were not suitable for other measurements of internal structures, such as cranium size.

All character counts and measurements of this specimen were within the range of those made for the holotype (male) and paratypes ($n = 6$ males, $n = 5$ females) of *B. lindbergi* provided in Ishiyama and Ishihara (1977; Table 1). Our specimen is the first record of *B. lindbergi* in Canadian Pacific waters and extends the verified range of this species southward in the eastern North Pacific to include Queen Charlotte Sound, Canada.

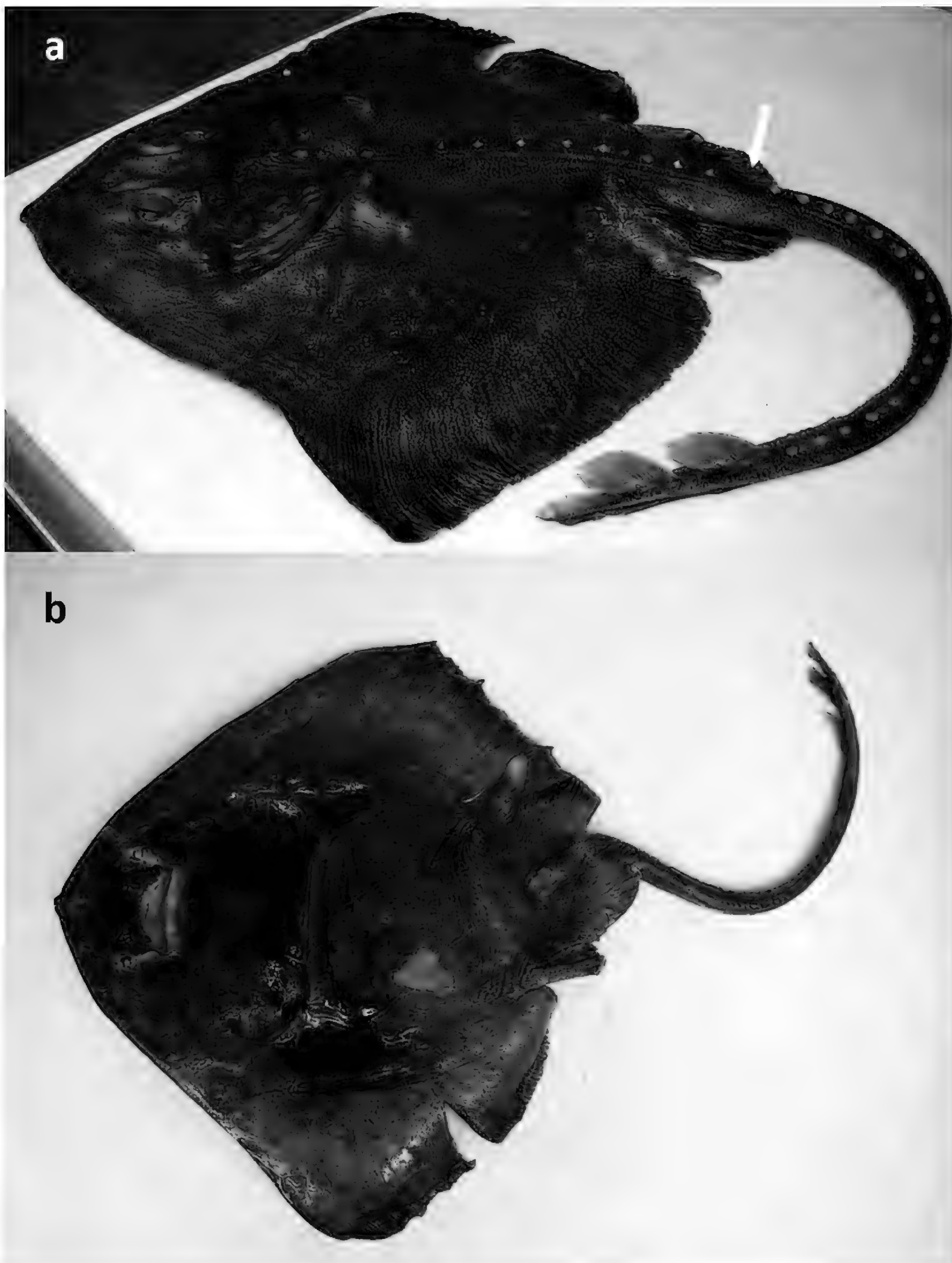


FIGURE 1. Commander Skate (*Bathyraja lindbergi*) collected 2 August 2009 in Queen Charlotte Sound, Canadian Pacific waters (RBCM 16401). a. Dorsal surface with grey-brown colouration; scapular thorns absent; mid-dorsal thorns present and strong; median tail thorns also strong along entire length of tail. Arrow indicates location of one broken thorn evident in pelvic region; base of thorn was intact. b. Ventral surface with grey colouration, darker around pectoral and pelvic fin margins; white colour surrounding mouth and nostrils; ventral surface of disc smooth and without denticles. Photos: T. Zubkowski.

TABLE 1. Character counts and measurements of Canadian Commander Skate (*Bathyraja lindbergi*) specimen collected in Canadian waters (RBCM 16401) along with those reported for the holotype (MTUF 21820) and paratypes (minimum–maximum range) reported in Ishiyama and Ishihara (1977).

Character	Holotype ♂	Paratypes (n = 11)	Canadian specimen ♀
Total length, mm	874	768–876	829
Disk width, mm	551	491–607	516
Head length, mm	134	131–153	140
Tail length, mm	482	391–488	437
Precaudal vertebrae	31	29–34	32
Caudal vertebrae	71	68–72	70
Total vertebrae	114	113–117	114
Nuchal thorns	4	3–5	4
Lumbar thorns	5	4–6	6
Tail thorns	25	20–28	23
Tooth rows on upper jaw	27	21–29	26
Pseudobranchial folds	17.5	15–17.5	16
As % of disk width			
Total length	158.6	144.3–160.7	160.7
Disk length	76.8	74.9–81.0	80.4
Tail length	87.5	79.3–88.0	84.7
As % of head length			
Preocular length	59.7	58.8–64.9	64.3
Interorbital length	29.1	23.5–27.0	27.4
Eyeball length	22.4	16.5–20.7	20.0
Spiracle length	22.4	17.3–21.4	19.2
Over first gill slits (female)	–	119.0–133.6	129.3
Eyeball length as % of			
Interorbital length	76.9	67.5–82.4	73.0
Preocular length	37.5	27.1–32.9	31.1
Spiracle length	100.0	83.3–113.8	104.2
As % of tail length			
Precaudal length	81.5	79.1–98.7	89.2
First dorsal fin origin to tail end	24.9	21.4–26.8	24.3
Post dorsal length	7.9	6.6–9.7	8.0

Author Contributions

Writing – Original Draft: J.K.; Writing – Review & Editing: J.K, G.M., and T.Z.; Investigation: J.K., G.M., and T.Z.; Formal Analysis: J.K. and G.M.

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Note

A Canadian range extension for Wormslug (*Boettgerilla pallens*; Gastropoda: Stylommatophora: Boettgerillidae)

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Catling, P.M., and B. Kostiuk. 2018. A Canadian range extension for Wormslug (*Boettgerilla pallens*; Gastropoda: Stylommatophora: Boettgerillidae). *Canadian Field-Naturalist* 132(3): 264–267. <https://doi.org/10.22621/cfn.v132i3.1993>

Abstract

The introduced Wormslug (*Boettgerilla pallens* Simroth, 1912) is reported from Quebec, Canada, for the first time, from two closely situated localities in Gatineau Park. It was previously reported from the Vancouver area of British Columbia and, very recently, from Newfoundland. Within the Americas, the species has been reported from northern California, Mexico, and Colombia, and, because it is easily overlooked, likely occurs elsewhere in North America, especially in the eastern United States. In Quebec, it was found in a natural Sugar Maple (*Acer saccharum* Marshall) woodland and an ornamental garden. Wormslug likely reached both sites with shrub plantings from commercial nurseries, probably quite recently, because the invasive spread of the species, worldwide, has occurred mostly during the last few decades. Although the woodland where it occurred is dominated by native plants, the gastropod fauna there is mainly introduced. Identification, characteristics, and ecology of Wormslug are discussed. The potential for impact on native soil and soil surface organisms, including native terrestrial slugs and snails, is noted.

Key words: Wormslug; *Boettgerilla pallens*; Quebec; introduced; invasive; slug; spread; distribution; ecology

During a general biodiversity reconnaissance in Gatineau Park, Quebec, in September and October 2017, we discovered two closely situated occurrences of Wormslug (*Boettgerilla pallens* Simroth, 1912). This largely subterranean, worm-like slug (Figure 1), which is native to southeastern Europe, has expanded its range remarkably over the past few decades (e.g., Kerney 1999; Reise *et al.* 2000; Maunder *et al.* 2017). The newly discovered populations in Quebec are ~3500 km east of previous known occurrences in the Vancouver area of British Columbia (Reise *et al.* 2000) and ~1790 km west of a recently reported occurrence in Newfoundland (Maunder *et al.* 2017). The nearest known United States location is in northern California (McDonnell *et al.* 2014), ~3800 km to the west. It is an easily overlooked species and likely occurs elsewhere in North America, particularly in the eastern United States.

Only two species of *Boettgerilla* are known, both originating in the Caucasus Mountains, east of the Black Sea. *Boettgerilla pallens* may also be native in the relatively nearby mountains of Crimea (Balashov and Baidashnikov 2012). Although *B. pallens* has expanded its world range dramatically during the last century, *Boettgerilla compressa* Simroth, 1910 has not yet been reported from outside of the southwestern Caucasus Mountains (Sysoev and Schileyko 2009). *Boettgerilla compressa* differs (Sysoev and Schileyko 2009) from *B. pallens* in that the adults are ~20 mm long when contracted instead of 10 mm long, pale brownish-yellow instead of pale grey, and laterally compressed across the back (hence the name) instead of equilaterally triangular (Simroth 1912: 121) to somewhat cylindrical. Al-

though our specimens seem best placed with *B. pallens*, and that is the species associated with all records of range expansion, we note that the distinctive features are size and age-related, and that *B. compressa* may benefit from additional taxonomic study.

The only other slug present in the general Gatineau Park region of Quebec that is likely to be confused with *B. pallens* is the pale greyish Pale Mantleslug (*Pallifera dorsalis* (A. Binney, 1842)). The latter differs in being shorter when extended, in lacking a keeled tail, and in having a rounded mantle that extends almost to the tip of the tail. *Boettgerilla pallens* is very slender and has a keel on the back half of its body extending from behind the mantle to the tip of the tail. In addition, the mantle has a different texture with concentric ridges (Figure 1a,b) and tapers to a broad point distally.

The adult Wormslugs found at the Meech Lake site in Gatineau Park were 20–45 mm long and 2–3 mm wide when extended. Most were light greyish with the front of the head, front of the mantle, keel, and tip of the tail being darker grey (Figure 1a). Two of the longest individuals, both 45 mm when extended, were a darker grey overall and had some brownish colouring (Figure 1b). Individuals that we thought likely to be juvenile were ~20 mm when extended and mostly white with yellowish internal organs visible through the whitish translucent body (Figure 1d). Size and colour are age-related in *B. pallens*, with “juveniles” being distinctly whitish (Gunn 1992; Rowson *et al.* 2014).

When picked up with forceps (or otherwise irritated) the body behind the mantle compressed laterally, becoming 1 mm thick in dorsal view (and 4 mm wide in

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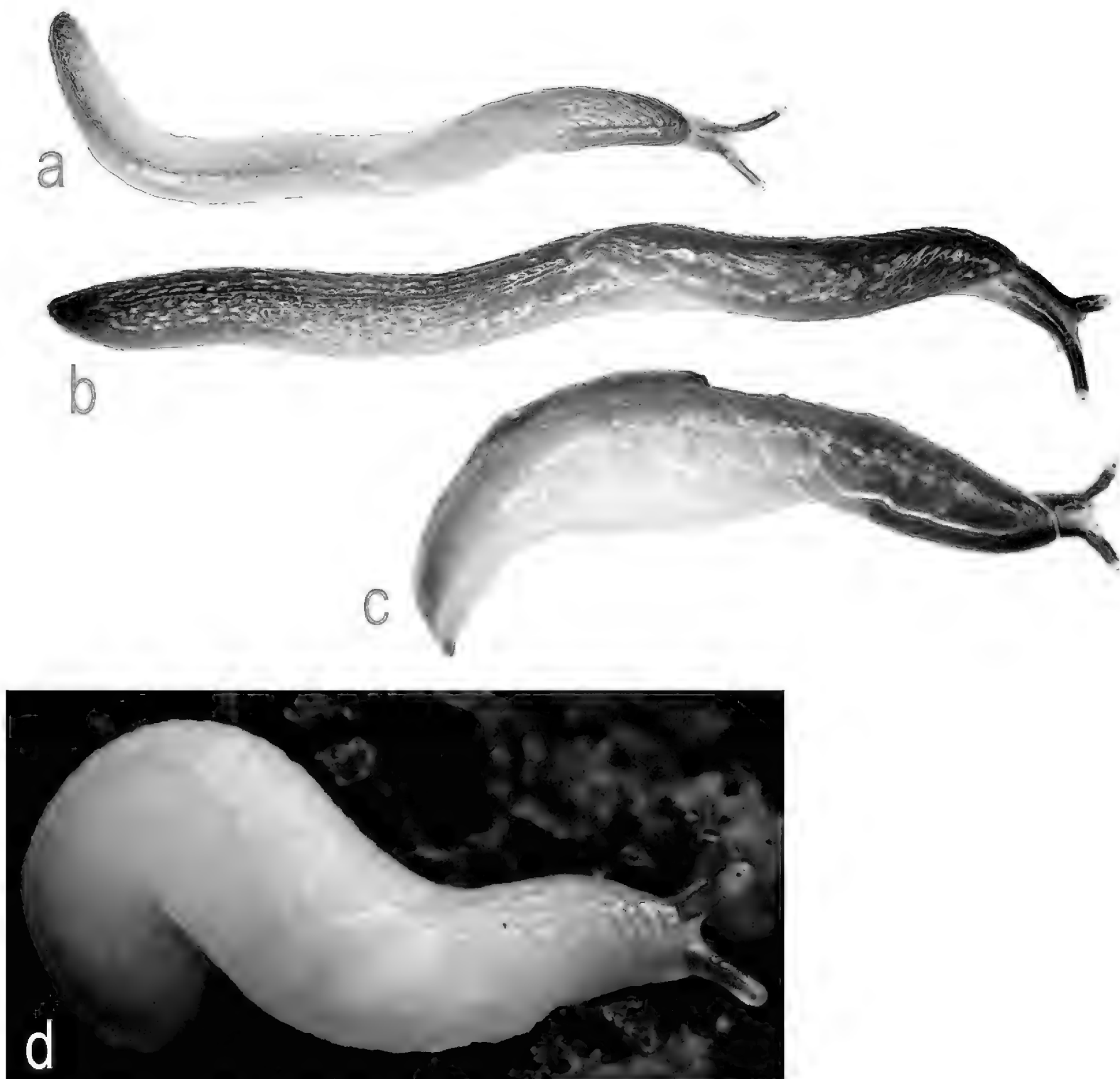


FIGURE 1. Wormslugs, *Boettgerilla pallens*, from Meech Lake, Gatineau Park, Quebec. a. Mostly pale grey and 30 mm when extended. b. Darker and brownish and 45 mm when extended. c. Same individual as b but with back half laterally compressed and keel raised as a thin, long dorsal fin. d. A whitish and semi-transparent juvenile Wormslug showing internal organs; the animal was 20 mm in length when extended. Photos: P.M. Catling and B. Kostiuk.

lateral view), and the keel became prominently raised (Figure 1c). When the head was touched, it withdrew under the mantle which extended and flattened or folded over the head like an envelope so that its sides met.

A number of illustrations are available in addition to our photographs (Figure 1) to assist in identification including Simroth (1912: Plate 3, Figure 50, Plate 8, Figure 32), Wiktor (1959: Figures 6 and 7, 1961: Figures 3–5), Reise *et al.* (2000: Figure 1), Barker and Efford (2004: Figure 6.8), Grimm *et al.* (2009: Plate 1), Sysoev and Schileyko (2009), Balashova and Baidashnikov (2012: Figure 1b), and Maunder *et al.* (2017: Figures 1–4).

Since expanding its range from its native Caucasus Mountains, apparently during the last 100 years, *B. pal-*

lens has been reported from much of central and western Europe, ranging north to Scandinavia (Kerney and Cameron 1979; Reise *et al.* 2000; Eversham 2012; Anderson 2016; Maunder *et al.* 2017). It is also known from the Canary Islands (Margry 2014). In the Americas, it has most recently been discovered in St. John's, Newfoundland (Maunder *et al.* 2017). Additional occurrences have been reported from southwestern British Columbia (Reise *et al.* 2000; Grimm *et al.* 2009; Maunder *et al.* 2017), California (McDonnell *et al.* 2014), Mexico (Araiza-Gómez *et al.* 2016), and Colombia (Hausdorf 2002).

In its introduced range, *B. pallens* occupies anthropogenic habitats, including gardens, greenhouses, semi-wild city parks, and plant nurseries. However, in the

Americas, in particular, it also occupies a number of “natural-looking habitats” (Maunder *et al.* 2017). It is said to have successfully penetrated forests and other natural habitats in recently colonized parts of Europe (Grimm *et al.* 2009).

At the Meech Lake, Gatineau Park site, the habitat where it was found is mesic woodland dominated by Sugar Maple (*Acer saccharum* Marshall) and Eastern White Cedar (*Thuja occidentalis* L.). Prominent herbs included: Blue-stemmed Goldenrod (*Solidago caesia* L.), Common Lady Fern (*Athyrium filix-femina* (L.) Roth ex Mertens), Drooping Woodland Sedge (*Carex arctata* Boott), Interrupted Fern (*Osmunda claytoniana* L.), Large False Solomon’s Seal (*Maianthemum racemosum* (L.) Link subsp. *racemosum*), Lindley’s Aster (*Symphyotrichum ciliolatum* (Lindley) Å. Löve & D. Löve), and Tall Rattlesnakeroot (*Nabalus altissimus* (L.) Hooker). This habitat is in a valley where a small stream cascades over granite boulders at the base of a steep north-facing slope.

These Wormslugs were found ~20–70 m along a trail from the parking area into natural forest. Although the forest showed no signs of recent disturbance, it was apparently subject to domestic cutting a little more than 100 years ago. The landscape may have been much more open at that time, as a consequence of this wood cutting. Although the habitat now appears essentially natural, the only terrestrial snails present (observed in a 1-h search in an area of 0.40 ha) were: the possibly introduced locally (Holarctic) Glossy Pillar (*Cochlicopa lubrica* (Müller, 1774); $n = 7$); possibly introduced (Holarctic) Black Gloss (*Zonitoides nitidus* (Müller, 1774); $n = 3$); and native Quick Gloss (*Zonitoides arboreus* (Say, 1817); $n = 6$). The slugs present were all introduced including Garden Arion (*Arion hortensis* Férussac 1819, *sensu lato*; $n = 50$); Dusky Arion (*Arion subfuscus/fuscus* (Draparnaud, 1805); $n = 1$); and Grey Fieldslug (*Deroceras reticulatum* (Müller, 1774); $n = 5$).

At the Old Chelsea Picnic Area site, also in Gatineau Park, the habitat where the Wormslugs were found was an ornamental garden dominated by a variety of planted perennials including: Variegated Goutweed (*Aegopodium podagraria* L.), daylilies (*Heemerocallis* spp.), geraniums (*Geranium* spp.), Eastern Purple Coneflower (*Echinacea purpurea* (L.) Moench), and Eastern White Cedar (*Thuja occidentalis* L.). This garden is more than 20 years old and has undergone many recent changes including additions of plants and rearrangement of paths. The terrestrial gastropod fauna (observed in a 0.5-h search in an area of ~0.10 ha) is mostly introduced, including: possibly introduced (Holarctic) Glossy Pillar ($n = 2$); introduced Hairy Hellicid (*Trochulus hispidus* (L., 1758); $n = 3$); possibly introduced (Holarctic) Black Gloss ($n = 1$); and introduced Garlic Glass-snail (*Oxychilus alliarius* (Miller, 1822); $n = 1$). The slugs present were: the introduced Grey Fieldslug ($n = 15$); and native or possibly introduced (Holarctic) Meadowslug (*Deroceras laeve* (Müller, 1774); $n = 1$).

All these Wormslugs were found under rocks or logs more or less buried in the soil. This species is known to use earthworm burrows (Gunn 1992; Shikov 2007) and we found them in rodent burrows, as well as other spaces in soil and debris. They have been reported to descend to 60 cm below the soil surface (Gunn 1992). Earthworms (all introduced) were frequent at both Gatineau Park sites, and there were no accumulations of decomposing leaf litter at either site, so no litter samples were collected or available to search for minute snail species.

Wormslugs typically spread by transport in soil associated with cultivated plants (Reise *et al.* 2000). In 1900, the Meech Lake site was part of the Blanchet Farm where pears, plums, and apples had long been introduced. Along the southern shore of Meech Lake, there are currently many cottages with plantings of introduced perennials, shrubs, and trees in rock gardens. These plantings were probably built up throughout the last century judging by the age of some cottages. Within the last two decades, the Blanchet homesite was converted into a parking lot for beach access, and various shrubs were planted around it, including Red-osier Dogwood (*Cornus sericea* L.), Rugosa Rose (*Rosa rugosa* Thunberg), and Nannyberry (*Viburnum lentago* L.). Although some of the planted shrubs are native, they all likely originated from commercial nurseries potentially harbouring non-native gastropods. The Chelsea site has perennials that were probably introduced from one or more commercial nurseries that also probably had populations of introduced gastropods (as all local nurseries do). Thus both occurrences are consistent with the general explanation for the spread of Wormslugs.

These burrowing slugs are said to feed on fungi, micro-organisms, roots, decaying vegetation, eggs of other gastropods, and possibly invertebrates (Barker and Efford 2004; Eversham 2012). They are also reported to appear at the surface at night and feed on medium-sized snails (Shikov 2007). Unlike many other slugs, they are said not to survive in captivity on oatmeal, mushrooms, and carrot (Eversham 2012). Although Wormslug has not definitely been implicated as an agricultural pest, there does seem to be a potential for impact on native soil and soil surface organisms including native terrestrial snails. It may spread rapidly as appears to be the case following initial detection elsewhere (e.g., Eversham 2012).

Voucher specimens

Canada, Quebec: Gatineau Park: North-facing slope at the west end of Meech Lake above the Blanchet homestead parking area at the start of Sentier des Loups, 45.5425°N, 75.9107°W, Sugar Maple woods by stream, 20 September 2017, P.M. Catling 2017120 and B. Kostjuk, two specimens preserved of eight – Canadian Museum of Nature (CMNML 2018-1704). Old Chelsea Picnic Area, 45.5012°N, 75.8128°W, ornamental gar-

den, 9 October 2017, *P.M. Catling 2017148 and B. Kostiuk*, one specimen preserved of three – Canadian Museum of Nature (CMNML 2018-1703).

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Stéphane Wojciechowski of Land Management, Gatineau Park issued permit 19365-1 for the collection of terrestrial gastropods in Gatineau Park. The park also provided facilities for a gastropod field workshop. John E. Maunder, Jeff Nekola, and Fred Schueler kindly commented on the manuscript.

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Spring food habits of Wolverine (*Gulo gulo*) in the Colville River watershed, Alaska

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Abstract

Wolverines (*Gulo gulo*) are relatively abundant on the North Slope of Alaska, an Arctic ecosystem dominated by tundra habitats that run north from the Brooks Range across a wide coastal plain to the Beaufort Sea. The region contains a range of potential Wolverine prey species, including ungulates (Caribou [*Rangifer tarandus*], Moose [*Alces americanus*]), Arctic Ground Squirrel (*Urocitellus parryii*), and both Soricidae and Cricetidae species. The seasonal composition of these, and other prey species, in the Wolverines' diet is not well understood. We collected Wolverine scats during spring (March–May) on the North Slope while tracking animals from snowmobiles and with helicopters that visited areas identified as of interest during ground surveys or using global positioning system collared animals. We analyzed prey remains in 48 scat samples based on hair, bone, and other prey fragments. We then calculated frequency of occurrence, percentage of occurrence, and weighted percent volume for each major prey category detected. We confirmed species identity of scats as Wolverine by amplifying the control region of the mitochondrial DNA. We estimated spring diet diversity and richness based on nine major prey categories detected in scats. Ungulates and cricetids together constituted 69% of the Wolverines' spring diet, with Snowshoe Hare (*Lepus americanus*) constituting 9%, fox (*Vulpes* spp.) 6%, Arctic Ground Squirrel 2%, birds 2%, American Beaver (*Castor canadensis*) less than 1%, and unknown 6%.

Key words: Wolverine; *Gulo gulo*; diet; food habits; frequency of occurrence; percentage of occurrence; volume of occurrence; diet richness; diet diversity; Alaska

Introduction

Wolverines (*Gulo gulo*) are known as “facultative scavengers” that alternate between hunting live prey, scavenging, and consuming previously cached food to fulfill their energy requirements (Magoun 1987; Banci 1994; Dijk *et al.* 2008; Dalerum *et al.* 2009; Koskela *et al.* 2013; Mattisson 2016). In the Arctic, Wolverines generally switch from killing and consuming cached ungulate carrion (e.g., Caribou [*Rangifer tarandus*]) in the winter, to hunting small mammals (e.g., Arctic Ground Squirrel [*Urocitellus parryii*]) during the summer (Magoun 1987; Dijk *et al.* 2008). Because habitat and prey species availability differ across the Arctic and across seasons, Wolverines likely adjust their diet according to available prey sources (Churchill 1955; MacDonald and Cook 2009; Lenart 2015). Variation of diet composition may reflect prey availability, which in turn may influence the distribution and abundance of Wolverines. In this study, we focus on spring diet composition during the transition from winter to summer, defined here as March through May, in the Colville River watershed of the Alaskan Arctic.

Across their range, Wolverines feed on a variety of prey species comprised primarily of ungulates (Moose [*Alces americanus*], Caribou) in North America and Europe (Landa *et al.* 1997; Dalerum *et al.* 2009; Koske-

la *et al.* 2013; Inman and Packila 2015). However, Wolverines also forage on small mammals, birds, and fish (Magoun 1987; Landa *et al.* 1997; Samelius *et al.* 2002; Shardlow 2013; Inman and Packila 2015). In the North American Arctic, in addition to ungulates, Wolverines feed on ptarmigan (*Lagopus* spp.), soricids (shrews), cricetids (voles, lemmings, mice), hare (*Lepus* spp.), and Arctic Ground Squirrels (Banci 1987; Mulders 2001). One study conducted on Alaska's North Slope investigated the Wolverines' seasonal diet composition in summer (May–August) and winter (September–April) near the Utukok River in the foothills of the Brooks Range, and found that Wolverines relied heavily on Arctic Ground Squirrel almost the entire year, except in midwinter (December–February) when their diet shifted to Caribou (Magoun 1987). Caribou undertake seasonal migrations and Moose reside at low densities on the North Slope of Alaska (Fancy *et al.* 1989; Carroll 2014; Tape *et al.* 2016), suggesting that Wolverines may need to rely on cached food or alternative prey sources when ungulates are scarce.

Information on the relative contribution of small prey such as cricetids, soricids, Snowshoe Hare (*Lepus americanus*), ptarmigan, and large prey in the Wolverines' diet across the Alaskan Arctic is lacking, but could contribute towards understanding how prey selection influen-

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ces Wolverine survival and reproductive success (Krebs *et al.* 2004; Persson 2005; Koskela *et al.* 2013). A lack of large ungulate prey coupled with dwindling food caches during early spring may force Wolverines to switch from ungulate carrion to other prey sources (Persson 2005). Investigating the relative presence of large versus small mammals (Cricetidae, Soricidae, Sciuridae, Leporidae) in the Wolverines' spring diet is an important step in understanding how Wolverines in the Arctic address a period of high energetic demands (Magoun 1987; Landa *et al.* 1997; Dalerum *et al.* 2009).

We collected Wolverine scats on the North Slope near Umiat, Alaska to determine spring diet composition of Wolverines in the foothills of the Brooks Range and Beaufort coastal plain (Figure 1). Our objectives were to describe the spring diet composition of Wolverines in our study area and compare the portion of that period's diet made up of small mammals versus ungulate prey.

Study Area

Our study took place in 2016 within 120 km of Umiat, Alaska in the National Petroleum Reserve-Alaska (NPR-A; Figure 1). On the southeast border of the NPR-A lies the Colville River corridor made up of flood

plain with shrubs such as alder (*Alnus* spp. Miller) and willow (*Salix* spp. L.). Northwest of the Colville River are rolling hills with steep cut drainages, composed of upland tundra vegetation such as Tussock Cottongrass (*Eriophorum vaginatum* L.) and mountain avens (*Dryas* spp. L.; Viereck *et al.* 1992). Further north, the land transitions from rolling hills to a flattened terrain filled with lakes and ponds, which extends north to the coast of the Beaufort Sea. This area is considered lowland tundra, containing Water Sedge (*Carex aquatilis* Wahlenberg) and other mesic plant species (Churchill 1955). At Umiat, average temperatures range from -30°C in February to 13°C in July (NOAA 2018). Average annual rain and snow accumulation are 13.9 cm and 84.3 cm, respectively.

While large ungulates, cricetids, soricids, other small mammals (e.g., Snowshoe Hare, Arctic Ground Squirrel), and birds are available as prey to Wolverines during spring (Table 1), their relative abundance may change over time and space (MacDonald and Cook 2009). Caribou are seasonally available as they migrate through the study area in spring and fall, residing near the coast in summer, and in the Brooks Range to the south in winter (Lenart 2015). Moose and Muskox (*Ovi-*

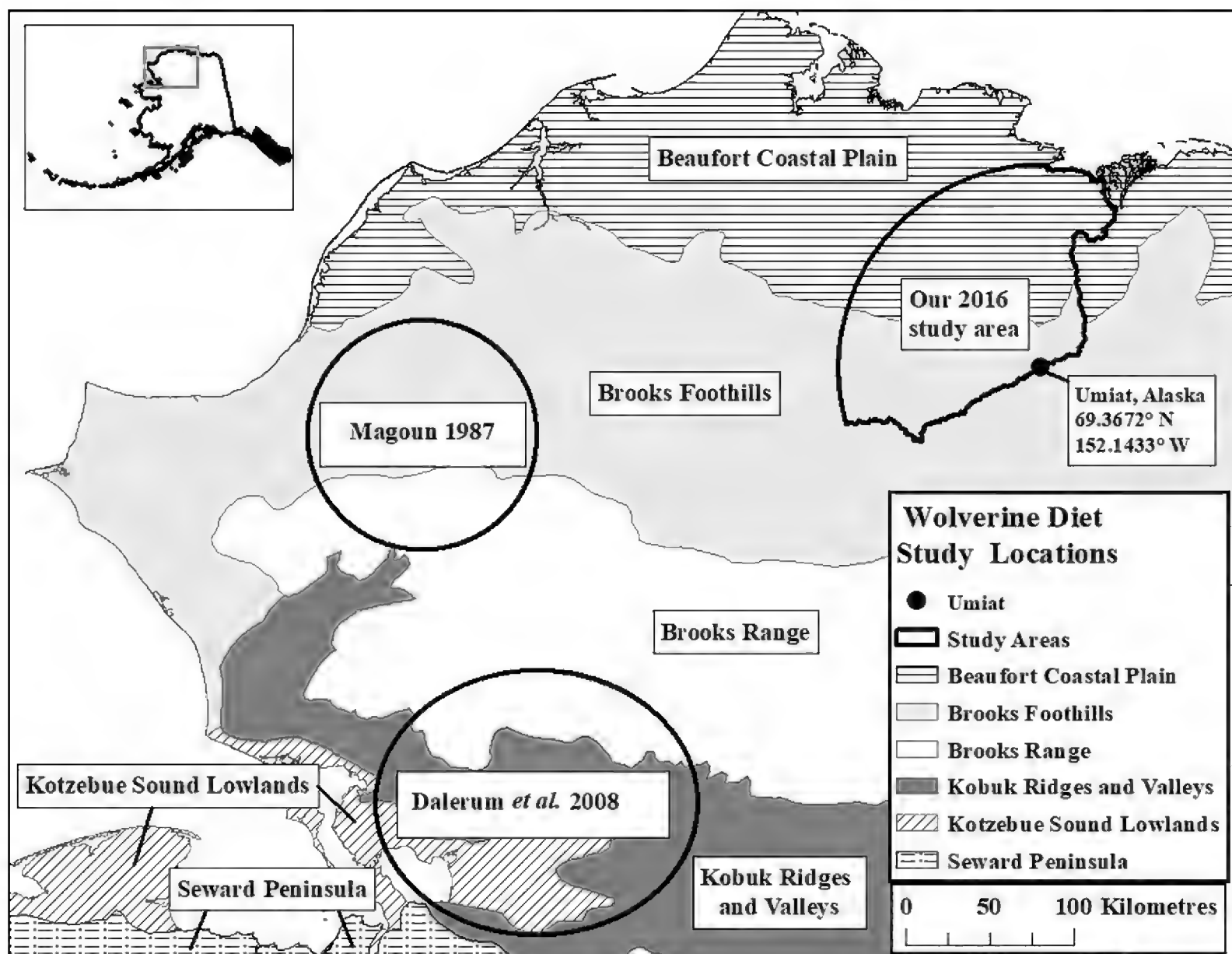


FIGURE 1. Wolverine (*Gulo gulo*) diet study areas compared to the ecoregions of northern Alaska, USA. Our 2016 study area took place within 120 km of Umiat, Alaska in the National Petroleum Reserve-Alaska.

bos moschatus) persist at low densities year-round, but Muskox only inhabit the northern portion of the study area near the Beaufort Sea (MacDonald and Cook 2009; Carroll 2014). Smaller prey that inhabit the study area year-round include: cricetids, soricids, Arctic Ground Squirrel, Snowshoe Hare, Willow Ptarmigan (*Lagopus lagopus*), and Rock Ptarmigan (*L. muta*; MacDonald and Cook 2009). Cricetids and soricids are active underneath the snow year-round, while Arctic Ground Squirrels hibernate, reducing the Wolverines access to these species in winter and early spring (Batzli and Sobaski 1980). In contrast, Snowshoe Hare and ptarmigan are available year-round. Wolverines are known to cache their prey, thus any species listed above may be consumed during winter and spring (Magoun 1987).

Methods

Scat collection

We followed Wolverine tracks by snowmobile 10 March–29 April 2016 to collect scats for diet analysis. We followed tracks opportunistically while maintaining a live-capture trap line, picking up scats from unknown individuals. When we encountered relatively fresh Wolverine tracks (e.g., not blown over, or covered with snow), we followed the track against the direction of travel to avoid harassing the animal. If tracks were older (e.g., blown over with snow) we followed the track in either direction. We stopped tracking when the animal travelled through terrain unnavigable by snowmobile, or when tracking conditions deteriorated. We recorded global positioning system (GPS) coordinates for each

scat collected. We recorded the location of Wolverine snow-holes encountered while tracking and returned to collect scats in late spring after the snow melted. At carcass sites, we collected all scats, but only included one randomly selected scat in our analysis to avoid pseudo-replication and the over-representation of the prey species at the carcass site (Marucco *et al.* 2008; Bacon *et al.* 2011).

We captured five Wolverines 6–26 April 2016 and affixed GPS collars (Tellus light model, Followit Sweden AB, Lindesberg, Sweden) programmed to record locations every 20 minutes. We captured three females including one juvenile and two reproductive females (with kits), one juvenile, and an adult male. Collars remained on animals until mid-summer when drop-off mechanisms were activated. In addition to scats collected while tracking unknown individuals, we collected scats from areas where collared Wolverines spent >20 minutes in an area <100 m², signifying an extended stay in a localized area where scat could be found (called a cluster). We returned to snow-holes and clusters on 29 May to collect scats.

We placed scats in Whirl-Packs® (Nasco, Fort Atkinson, Wisconsin, USA) and stored them at temperatures ranging from 4°C to –35°C while in the field (10 March –29 April, and 29 May). After leaving the field, we stored samples in a –20°C freezer for a maximum of 1.5 months.

We radio-tracked collared Wolverines with fixed-winged aircraft 13–22 May to observe feeding behaviour. We watched for visually identifiable prey (e.g., a

TABLE 1. List of potential prey items available in late winter and early spring to Wolverines within the National Petroleum Reserve-Alaska (MacDonald and Cook 2009).

Family	Common name	Scientific name
Bovidae	Muskox	<i>Ovibos moschatus</i>
Canidae	Gray Wolf	<i>Canis lupus</i>
	Arctic Fox	<i>Vulpes lagopus</i>
	Red Fox	<i>Vulpes vulpes</i>
Cervidae	Moose	<i>Alces americanus</i>
	Caribou	<i>Rangifer tarandus</i>
Cricetidae	Peary Land Collard Lemming	<i>Dicrostonyx groenlandicus</i>
	Brown Lemming	<i>Lemmus trimucronatus</i>
	Singing Vole	<i>Microtus miurus</i>
	Tundra Vole	<i>Microtus oeconomus</i>
	Northern Red-backed Vole	<i>Myodes rutilus</i>
Felidae	Lynx	<i>Lynx canadensis</i>
Leporidae	Snowshoe Hare	<i>Lepus americanus</i>
Mustelidae	Wolverine	<i>Gulo gulo</i>
	Ermine	<i>Mustela erminea</i>
	Least Weasel	<i>Mustela nivalis</i>
	Willow Ptarmigan	<i>Lagopus lagopus</i>
Phasianidae	Rock Ptarmigan	<i>Lagopus muta</i>
	Arctic Ground Squirrel	<i>Urocitellus parryii</i>
Sciuridae	Cinereus Shrew	<i>Sorex cinereus</i>
Soricidae	Tundra Shrew	<i>Sorex tundrensis</i>
	Barren Ground Shrew	<i>Sorex ugyunak</i>
	Holarctic Least Shrew	<i>Sorex minutissimus</i>
	Brown Bear	<i>Ursus arctos</i>
Ursidae	Polar Bear	<i>Ursus maritimus</i>

Moose carcass), and observed hunting behaviour (e.g., hunting small prey). We recorded time, location, colored animal's identity, and observed prey or behaviour.

Scat analysis

We confirmed identification of each scat as Wolverine with faecal DNA analysis, because tracking trails and clusters also had sign of other predators (e.g., foxes). We used three methods to sample faecal DNA from each scat. First, we scraped each scat using two flat-sided toothpicks and placed each into a coin envelope. Second, we removed 1 mL of faecal material from each scat and placed it into a vial. Finally, we swabbed each scat with a sterile cotton-tipped swab and placed it into a separate vial. We sent all samples to the Rocky Mountain Research Station, National Genomics Centre for Wildlife and Fish Conservation in Missoula, Montana to verify the species identity. We used the QIAGEN QIAamp Fast DNA Stool Mini Kit (QIAGEN Inc., Valencia, California, USA) following the manufacturer's instructions for DNA extraction. We amplified the control region of mitochondrial DNA (mtDNA) for species identification following Schwartz *et al.*'s (2007) methods for processing samples.

Following DNA sampling, we transferred individual scats into nylon mesh stockings and washed them on gentle cycle in a Haier HLP23E compact washing machine (Haier Appliances, Rapid City, South Dakota, USA). We washed scats for 2–3 cycles until the water ran clear (indicating the removal of the faecal matrix material) and air-dried samples for 48 h. We weighed each scat and identified prey remains by comparing microscopic qualities of medulla, cortex, and cuticular scale patterns of mammalian hairs to published keys (Moore *et al.* 1974; Carlee and Horelick 2011), and by comparing hair, teeth, claw, and bone fragments to reference specimens on loan from University of Alaska Museum of the North, Fairbanks, Alaska. We identified prey remains to species level or nearest taxonomic grouping if remains were highly degraded. We visually estimated the proportion of each prey type present in each scat, rounded to the nearest 5%. We also sub-sampled scats after determining the proportion of the scat belonging to each prey category. Of the scats that contained suspected cricetids and soricids, we collected 15–30 hairs to determine species identification through DNA analysis.

We used methods from Dijk *et al.* (2007) and the recommendations of Klare *et al.* (2011) to characterize Wolverine diet. Frequency of occurrence (FO) was calculated from the binary occurrence of each prey item in each scat, and represents the percentage of the total sample size containing each prey item:

$$FO_i(\%) = \frac{n_i}{N} \times 100$$

where n_i is the number of scats containing species i and N represents the total number of scats (Ciucci *et al.* 1996).

Percentage of occurrence (PO) is calculated from binary occurrence data that represents the percentage of the total prey occurrences containing each prey item:

$$PO_i(\%) = \frac{n_i}{\sum n_i} \times 100$$

where n_i is the number of scats containing species i . Finally, we calculated weighted volume (VOL) to determine the relative importance of prey in the diet in the absence of a biomass calibration (Klare *et al.* 2011).

Weighted volume is the sum of percent volume of each prey item in scats, divided by the total number of scats:

$$VOL_i(\%) = \frac{\sum v_i}{N} \times 100$$

where v_i is the proportion of each scat containing species i .

Scats collected while tracking individual Wolverines were treated as individual sample units. Scats collected from individual snow-holes and clusters were combined and treated as a single sample unit, because the large piles of scats collected at clusters, deposited by an unknown number of individuals, made it difficult to differentiate among individual scat samples. For scats collected at clusters, v_i was equal to the proportion of the total scat volume at a cluster.

Weighted volume was calculated for each prey item detected in scats. We then grouped prey items into one of nine major prey categories and calculated weighted volume of each major prey category in scats. The nine prey categories were: ungulate, Snowshoe Hare, Arctic Ground Squirrel, cricetids and soricids, birds (Aves), fox, American Beaver, unknown (including any unidentifiable remains), and other (consisting of vegetation, gravel, and woody debris). Items in the "other" category were expected to be incidentally ingested as a result of digging up food caches or excavating small mammal burrows. Although Wolverines have been documented to consume vegetation and berries, we assumed vegetation was incidentally ingested while feeding (Lofroth *et al.* 2007) or picked up during collection of scats. Thus we dismissed it from our analysis.

We estimated diet richness as the overall number of items in the diet, and diet diversity, which indexes heterogeneity and accounts for relative abundance of each item in the diet (Krebs 1999). We estimated diet diversity using the Shannon-Wiener diversity index (H'), whereby the higher the index value, the more evenness in use across all resources:

$$H' = \sum \hat{p}_i \ln \hat{p}_i$$

where p_i is the total proportion of species i in the sample (Colwell and Futuyma 1971). We estimated 95% CI for diet richness, diversity, and volume of each of the nine major prey categories based on 1000 bootstrap re-samplings of scat data (Manly 2006).

We used rarefaction to assess how diet diversity and richness varied with sample size (Krebs 1999). Rarefaction uses bootstrap resampling techniques to subsample from the initial dataset (without replacement) and estimate the mean and variance of the desired index (e.g., diversity, richness) for each sample size, n , from one to the maximum number of scat samples. We generated rarefaction curves based on 1000 bootstrap runs. Diet indices and bootstrapping and rarefaction analyses were calculated in Program R v 3.0.1 (R Development Core Team 2014).

Results

Scat collection

We collected 104 scat samples while tracking individual Wolverines from 10 March to 29 April ($n = 83$) and first visited GPS-identified clusters on 29 May ($n = 22$; Figure 2). We followed 64 km of tracks, collecting 83 scats during 30 tracking events. We collected 21 scats from 20 GPS-cluster sites (14 snow-holes monitored by motion-activated cameras and six clusters detected by GPS collar locations). We also collected 29 scats from near a Moose carcass.

Faecal DNA analysis confirmed 70 of the 104 scats we collected as Wolverine, 23 as Red Fox (*Vulpes vulpes*), three as Arctic Fox (*Vulpes lagopus*), and eight with poor DNA quality that precluded identification. Of

the 29 scats collected at the Moose carcass, 15 were identified as Wolverine, and we randomly chose one of these scats to include in our analysis (Marucco 2008; Bacon *et al.* 2011). We combined 15 of the scats collected at clusters identified as Wolverine into eight cluster scat samples, for a final sample size of 48 (40 from tracking and eight from GPS-clusters). Of the scats containing cricetids ($n = 25$), three contained Peary Land Collared Lemming (*Dicrostonyx groenlandicus*), two Brown Lemming (*Lemmus trimucronatus*), two Singing Vole (*Microtus miurus*), and others contained hairs that were non-cricetid or had poor quality DNA, preventing species identification. No soricids were found in scats.

Scat analysis

We classified prey remains and scat contents as one of 11 categories, five of which we identified to the species level (Figure 3): unknown ungulate (too degraded to distinguish between Moose or Caribou), Moose, Caribou, unknown carnivore (too degraded to determine species), fox, American Beaver, Snowshoe Hare, Arctic Ground Squirrel, cricetids, birds, and unknown (unidentified bone and other debris). We did not attempt to identify feather remains beyond the “bird” category because the majority of feathers were too highly degraded for species identification, although we expect that they were predominantly ptarmigan based on our

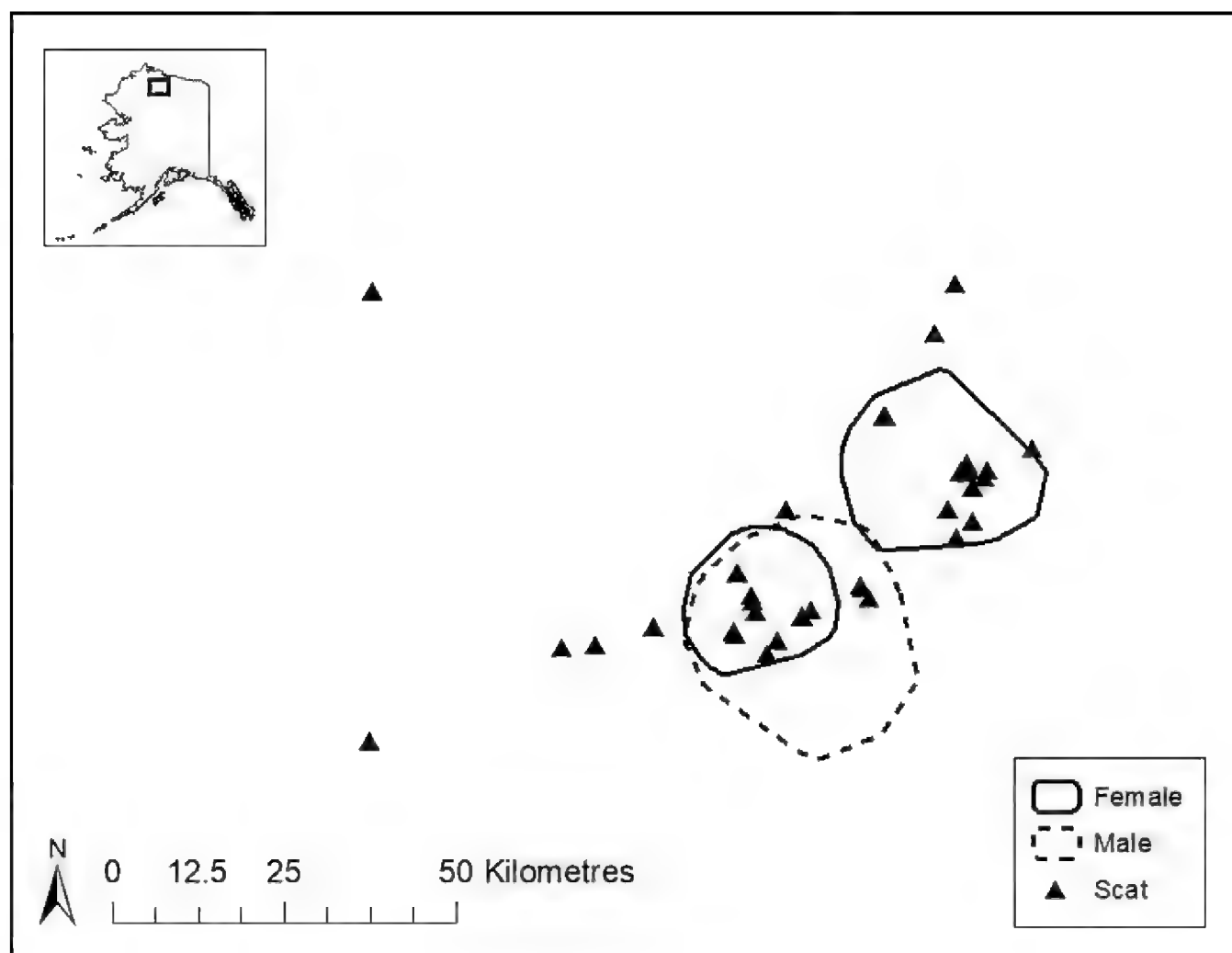


FIGURE 2. Locations of Wolverine (*Gulo gulo*) scats collected and home ranges of three Wolverines (one male, two female) near Umiat, Alaska, USA 10 March–29 April, and 29 May 2016. We collected 67 scats later confirmed through DNA analysis as Wolverine. Home ranges represent 95% minimum convex polygons. Locational details have been purposely omitted.

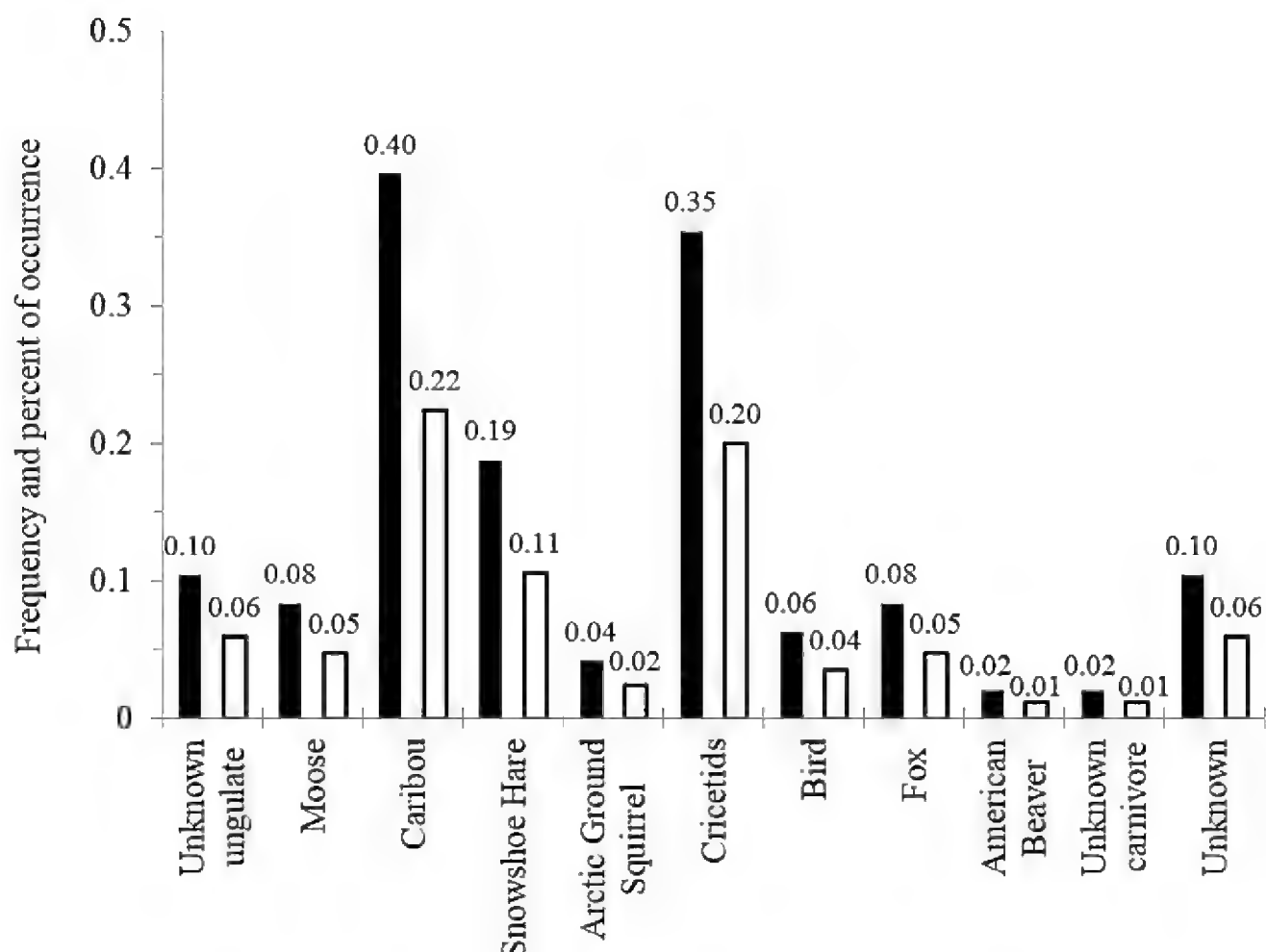


FIGURE 3. Frequency and percent of occurrence (FO and PO, respectively) of all prey species detected in combined Wolverine (*Gulo gulo*) scats ($n = 48$) collected near Umiat, Alaska, USA, 10 March–29 April, and 29 May 2016. Closed bars represent FO and open bars represent PO. Prey detected includes: unknown ungulate (Moose [*Alces americanus*], Caribou [*Rangifer tarandus*]), Moose, Caribou, Snowshoe Hare (*Lepus americanus*), Arctic Ground Squirrel (*Uroditellus parryi*), cricetids (Brown Lemming [*Lemmus trimucronatus*], Peary Land Collared Lemming [*Dicrostonyx groenlandicus*], Singing Vole [*Microtus miurus*]), bird (Aves), fox (Red Fox [*Vulpes vulpes*], Arctic Fox [*Vulpes lagopus*]), American Beaver (*Castor canadensis*), unknown carnivore (Carnivora), and unknown. Vegetation (FO = 0.25, PO = 0.14) and woody debris (FO = 0.06, PO = 0.04) not shown.

observations while in the area and consumption by Wolverines elsewhere.

Raw measures of FO and PO indicated that the four most commonly occurring items in scats were Caribou, cricetids, vegetation (assumed to be incidentally ingested during feeding or scat collection and not considered in further analyses), and Snowshoe Hare (Figure 3). Ranking prey items by volume indicated that the three most abundant identifiable items were Caribou, cricetids, and Snowshoe Hare. Cricetids and Caribou collectively represented 55% volume of the diet (Figure 3). Bootstrapped estimates of volume (mean \pm SD) of each of the nine major prey categories indicated that ungulates (0.49 ± 0.07) and cricetids (0.20 ± 0.05) were the two primary prey resources (Figure 4). Arctic Ground Squirrel (0.02 ± 0.03) made a minor contribution to the diet.

Mean diet richness was eight resource categories (8.43 ± 0.81 ; Figure 5a). Mean Shannon-Wiener diversity index for scats was 1.75 ± 0.11 . Rarefaction curves showed that mean diet richness continued to increase up to a sample size of about 40 scats, after which the rarefaction curve began to approach an asymptote (Figure 5a). Rarefaction of mean diet diversity showed that the

diversity curve approached an asymptote after a sample size of about 20 (Figure 5b).

We observed five instances of active hunting by Wolverines between 13 and 22 May. Three events were of an adult male and two events of a single adult lactating female, exhibiting pouncing behaviour we attributed to hunting small mammals. We observed four out of five instances of hunting behaviour in tussock habitat.

Discussion

This study represents the second study of spring Wolverine diet north of the Brooks Range in Alaska (following Magoun 1987) and the first in the Colville River watershed. We documented a high prevalence of ungulates and cricetids in Wolverine scats, indicating the importance of these resources during spring. We also detected various predators (e.g., foxes), mid-size prey (Snowshoe Hare), and bird remains, documenting that Wolverines use a variety of prey types on the North Slope. Although we detected American Beaver in our scats, we attribute this to bait used by local trappers in the area as they are not a common species north of the Brooks Range of Alaska, although their range is increasing (MacDonald and Cook 2009; Tape *et al.* 2018).

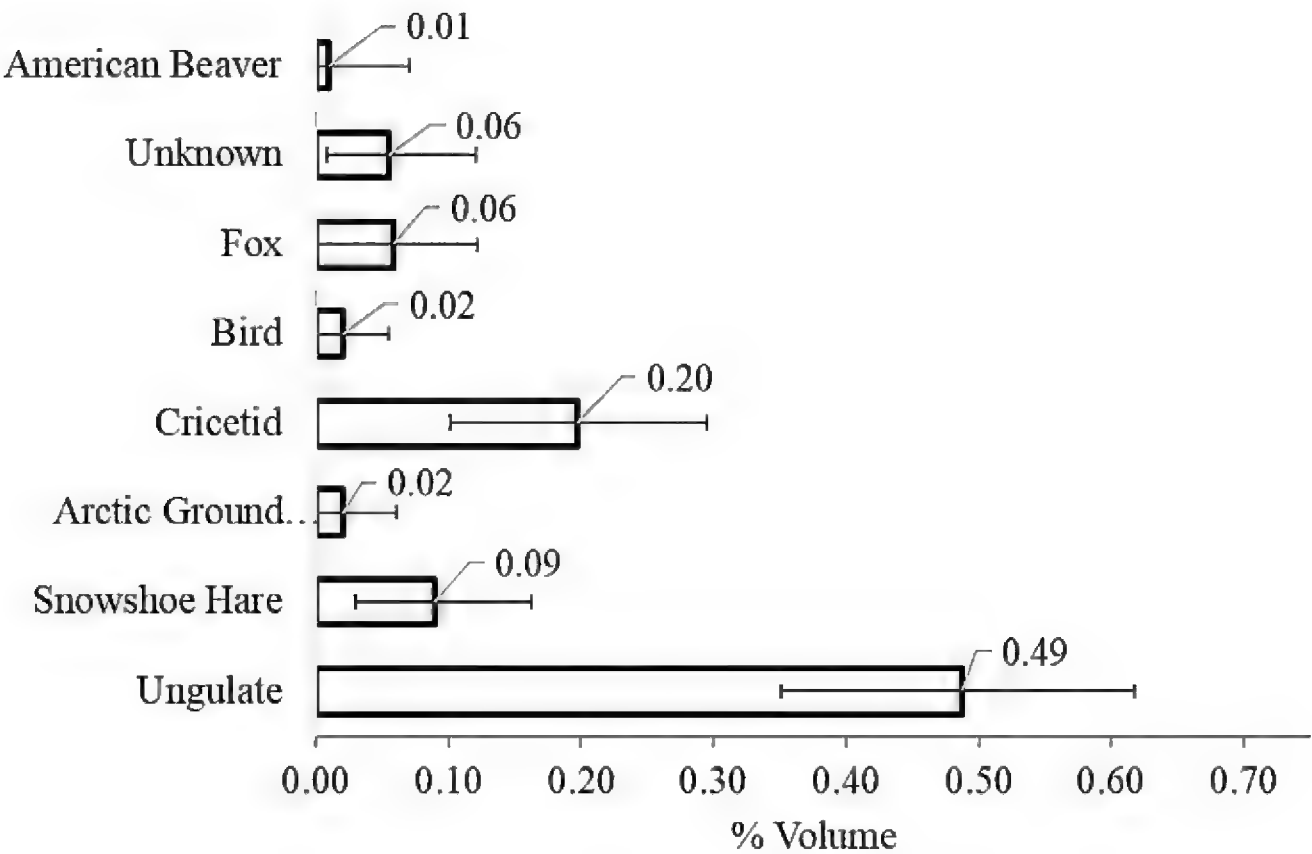


FIGURE 4. Volume and 95% CI for each of eight prey categories detected in Wolverine (*Gulo gulo*) scats collected while tracking and from GPS clusters near Umiat, Alaska, USA, 10 March–29 April, and 29 May 2016. We weighed the samples then conducted an ocular estimate of the percentage of each prey item in the scat to determine percent volume. We estimated CI from 1000 bootstrap re-samplings. Prey detected includes: ungulate (Moose, [*Alces americanus*], Caribou [*Rangifer tarandus*]), Snowshoe Hare (*Lepus americanus*), Arctic Ground Squirrel (*Urocitellus parryi*), cricetids (Brown Lemming [*Lemmus trimucronatus*], Peary Land Collared Lemming [*Dicrostonyx groenlandicus*], Singing Vole [*Microtus miurus*]), bird (Aves), fox (Red Fox [*Vulpes vulpes*], Arctic Fox [*Vulpes lagopus*]), Ermine (*Mustela ermine*), American Beaver (*Castor canadensis*). Other (7%, including vegetation and woody debris) not shown.

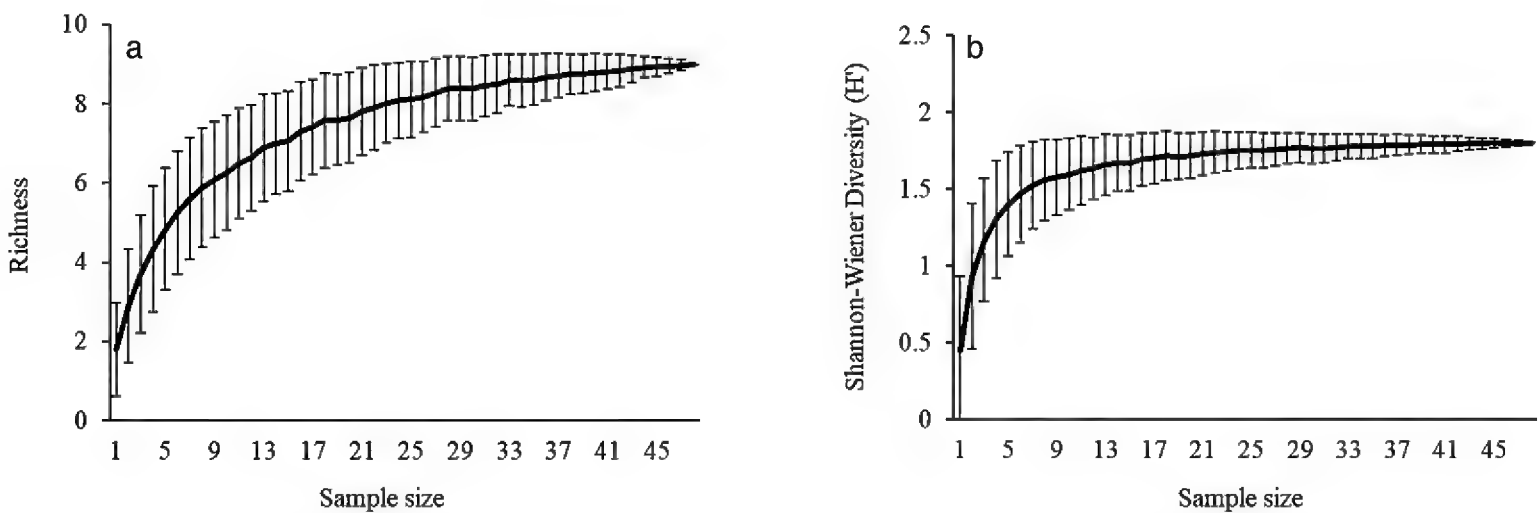


FIGURE 5. Rarefaction curves exhibiting the influence of sample size (x-axis) on Wolverine (*Gulo gulo*) diet richness (a) and diversity (b) estimated for scats collected near Umiat, Alaska, USA, 10 March–29 April, and 29 May 2016. Error bars show one SD estimated from 1000 bootstrap re-samplings of data.

Ungulates made up the largest portion of the Wolverines’ diet based on our scat frequency and percentage of occurrence, and volume, which is similar to previous studies in North America and Fennoscandia (Lofroth *et al.* 2007; Dalerum *et al.* 2009; Koskela *et al.* 2013; Inman and Packila 2015). Moose contributed to diets of Wolverines in our study area, however due to their low abundance they likely are not a reliable prey source. The only Moose carcass we found provided an abundance of food for local Wolverines, but Caribou provide more overall biomass when available. Another Wolver-

ine diet study in the southwestern Brooks Range (Dalerum *et al.* 2009), also found that Wolverines mainly subsisted on Caribou throughout the winter, despite the Western Arctic Caribou Herd’s only seasonal availability (Lenart 2015). Dalerum *et al.* (2009) found that Caribou made up >50% of stomach and colon contents in Wolverine carcasses. Because winter Caribou distribution on the North Slope is inconsistent between years (Dau 2015; Lenart 2015), access to Caribou in the winter can be supplemented from food caches. We were unable to determine whether prey remains were from cach-

ing their own prey, scavenging other predator kills (such as from Gray Wolf [*Canis lupus*]), or from actively hunting. Obtaining this information would help reveal how Wolverines in our study area manage seasonally abundant ungulates compared to other prey sources (e.g., Arctic Ground Squirrel) that are less accessible in late winter. Similar to other studies basing diet inference on scats, only hair, bone, and feathers are available to determine FO and PO. This may underestimate a large prey item where large amounts of muscle are digested yielding a potentially smaller proportion of hair to biomass consumed. Other items, such as bird eggs may not be identified, but are known to be eaten by Wolverines (Magoun 1987; Samelius *et al.* 2002).

Although ungulates represent a significant portion of the Wolverines' diet in our and other studies (e.g., Mulders 2001; Dalerum *et al.* 2005, 2009; Lofroth *et al.* 2007; Inman and Packila 2015), cricetids are clearly another important prey. Cricetids composed the second highest frequency and percentage of occurrence, and volume for overall diet in our study. We also observed behaviour in spring consistent with hunting small prey, highlighting their potential significance as a spring food resource. Cricetid populations are irruptive and fluctuate over various temporal and spatial scales influencing their availability to Wolverines (Krebs and Myers 1974). The high proportion of cricetids detected in our Wolverine scats may reflect an abundance of cricetids throughout the study area. Wolverine scats could also contain a large proportion of cricetids because Wolverines preferentially selected them (Manly *et al.* 2002). Wolverines could increase their use of cricetids when snow begins to melt in the spring exposing subnivean prey at a time when the tundra tussock habitat is flooding with meltwater (as observed for the animals we saw hunting). However, without a measure of small mammal and ungulate abundance, it is unclear if Wolverines select for these prey resources on the North Slope, or adjust their intake based on availability alone during spring.

Cricetids, Snowshoe Hare, and Arctic Ground Squirrel collectively constitute 30% volume of spring Wolverine diet in our study. However, the role of small prey in Wolverine population dynamics is poorly understood and could be significant given the timing of availability relative to reproduction (Inman *et al.* 2012). Small mammal abundance in our area contributes to the diets of reproducing female Wolverines, when ungulates are only seasonally available, or as cached carrion. The availability and use of ungulates versus small mammals could influence Wolverine survival and reproductive success (Krebs *et al.* 2004; Persson 2005; Koskela 2013; Petersen 2014). Access to prey is particularly important when females are under increased energetic stress in late winter through summer while nursing and provisioning young with prey (Inman *et al.* 2012; Koskela 2013).

Future studies would benefit from determining diet composition of individual Wolverines to compare diet among home ranges. For example, a Wolverine that has an established territory in a riparian area may exclude another individual from access to a Moose carcass, thereby forcing the individual to find other prey sources. Our satellite collared Wolverines (R.D. unpubl. data), along with other radio tracking studies (Dawson *et al.* 2010; Persson *et al.* 2010), showed that Wolverines exhibit intrasexual territoriality, which likely precludes individuals of the same sex from accessing resources in neighbouring territories. Differences in diet among individual Wolverine territories could provide useful information on small-scale controls of population dynamics among habitat types, sex and age classes, and seasons.

Our work in the spring does not allow us to make inferences about summer diet. However, cricetids and Arctic Ground Squirrel may both be easier to hunt in summer months due to lack of snow cover and could be an important resource for Wolverine kits. In southern Norway, an abundance of cricetids in summer increased Wolverine kit survival (Landa *et al.* 1997). In addition, Arctic Ground Squirrel was an important diet resource for Wolverines on the western portion of the North Slope (Magoun 1987). Future studies would benefit from documenting summer Wolverine diets for kits and adults across a broader area, to determine the reliance on cricetids and Arctic Ground Squirrel, and their relation to Wolverine population dynamics.

Arctic Ground Squirrel represented only a small portion of the spring Wolverine diet in our study area, which differs from Magoun's (1987) findings, but may be confounded with the timing of our sampling. Near the Utukok River in the western portion of the North Slope, Wolverines fed on Caribou in mid-winter (December–February), but primarily fed on Arctic Ground Squirrel the rest of the year (Magoun 1987). Scats collected at the same time also contained large quantities of soil, likely from Wolverines digging up cached or hibernating Arctic Ground Squirrels (Magoun 1987). We observed negligible soil in the scats we sampled. However, the low frequency and percentage of occurrence and volume of Arctic Ground Squirrel in our analysis compared to Magoun (1987) could also relate to a difference in Arctic Ground Squirrel abundance and emergence dates between study areas. Our study area contains well drained soils preferred by Arctic Ground Squirrels, but their abundance is unknown (Barker and Derocher 2010). Assessing Arctic Ground Squirrel abundance and emergence throughout the area could aid interpretation of differences in the reliance on ground squirrels according to their activity and availability. This may be particularly important given the progressively earlier spring melt and potentially earlier availability of ground squirrels and cricetids through reduced snow pack (IPCC 2013). Furthermore, ground squirrels may increase in density in some well-drained

areas as permafrost thaws in these northern ecosystems (Wheeler and Hik 2013).

To our knowledge, no other studies have used the Shannon-Wiener diversity index to calculate Wolverine diet diversity. We have no basis for comparing heterogeneity in resource use on the North Slope to other areas but monitoring how diet diversity changes over time or compares between areas could indicate differences in foraging strategies over time or among Wolverine populations. Future studies might consider adding this metric to their analysis to quantify how differences in resource use vary with the number of prey types in the diet. According to our rarefaction analysis, our sample size for diet richness may have been inadequate to provide accurate estimates of the average number of resources used by Wolverines. Future diet studies on the North Slope should consider increasing sample size to determine the full range of resources used by Wolverines.

A quantitative assessment of use versus availability would also provide improved insights into factors driving Wolverine prey selection, such as increased cricetid abundance, decreased ungulate abundance, or by the snowpack conditions affecting how cricetids and Arctic Ground Squirrels are accessible as the snowpack melts. Increased food availability corresponded with increased reproductive success of female Wolverines in Sweden (Persson 2005), thus, changes in food availability that influences reproductive success is a mechanism that could ultimately influence Wolverine abundance.

Author Contributions

Writing—Original Draft: R.D., K.S., and M.R.; Writing—Review & Editing: R.D., K.S., M.R., T.G., and K.P.; Conceptualization: R.D., M.R., and K.S.; Investigation: R.D., T.G., K.S., and K.P.; Methodology: K.S., R.D., and T.G.; Formal Analysis: K.S. and K.P.; Funding Acquisition: M.R.

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Use of stabilized thaw slumps by Arctic birds and mammals: evidence from Herschel Island, Yukon

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Abstract

As evidenced by animal sign (scat, active nests, nesting materials, rodent runways) observed across five stabilized retrogressive thaw slumps and two areas of undisturbed upland tundra, Arctic birds and mammals on Herschel Island, Canada, use stabilized thaw slumps differently than undisturbed tundra. Rodent winter nests and scat were found exclusively in undisturbed tundra and at a 250-year-old stabilized thaw slump site, whereas rodent runways and Semipalmated Plover (*Charadrius semipalmatus*) nests were found exclusively at 10- and 20-year-old stabilized thaw slump sites. Bird scat was found in each tundra type, but was most common in the youngest sites, and the number of observations decreased with increasing site age. Caribou (*Rangifer tarandus granti*) scat was found at all sites, whereas Muskox (*Ovibos moschatus*) scat was not found at 20-year-old sites and was most common in undisturbed tundra. To our knowledge, these observations are the first examples of birds and mammals using stabilized thaw slump habitat of different ages, and they provide new avenues of research for Arctic wildlife biologists concerned with the adaptation of these animals to permafrost disturbance and the resulting changes in vegetation cover.

Key words: Arctic; wildlife; thaw slump; Herschel Island; disturbance

Introduction

Retrogressive thaw slumps are among the most widespread thermokarst forms in the western Arctic, and each slump changes the physical and biotic characteristics of hectares of land (Mackay 1963; Cray and Pollard 2015). On Herschel Island, Yukon, Canada (69°36'N, 139°04'W, an area of 108 km²), there are over 100 active thaw slumps, and, since the 1950s, thaw slumps in the western Arctic have been increasing in both area and number (Lantuit and Pollard 2008; Lantz and Kokelj 2008). Permafrost disturbances and related changes in flora may affect the spatial extent of fauna disproportionately by creating habitat heterogeneity that may alter how animals use the landscape (Forbes *et al.* 2001). By creating numerous large, discrete disturbances with distinct vegetation communities caused by the different age classes of the stabilized slumps (Cray and Pollard 2015), retrogressive thaw slumping and the associated stages of revegetation alter the tundra landscape; as the incidence and extent of these slumps increase, it becomes increasingly important to assess the potential consequences for wildlife.

Study Area

Part of the Yukon Coastal Plain, Herschel Island's mosaic of terrestrial, wetland, and littoral habitats is visited by diverse populations of migrating and nesting waterfowl, passerines, shorebirds, and raptors, as well as Porcupine Caribou (*Rangifer tarandus granti*) and Muskox (*Ovibos moschatus*). Of the 121 bird species recorded on Herschel Island, 46 use it as a breeding site

(Yukon Bird Club 2015). The island is especially important as breeding habitat, as numerous Arctic-breeding species, particularly shorebirds, are in dramatic population decline (Gratto-Trevor *et al.* 2011). The four common small mammals recorded there are Northern Collared Lemming (*Dicrostonyx groenlandicus*), Brown Lemming (*Lemmus trimucronatus*), Tundra Vole (*Microtus oeconomus*), and Arctic Ground Squirrel (*Spermophilus parryii*; Krebs *et al.* 2011, 2012). These species are a fundamental part of the Arctic food web, as they are a food source for various avian and mammalian predators (Krebs *et al.* 2012). Small portions of the Porcupine Caribou herd spend time on Herschel Island, particularly from late April through August, with herds ranging in size from 21 to 75 individuals including bulls, cows, calves, and yearlings; in some years, Caribou have also been observed calving on the island (Cooley *et al.* 2012).

Methods

We recorded animal sign (scat, nests, rodent runways) in July 2011 from a total of 579 1 m × 1 m quadrats (Table 1) used in a vegetation community development study on slump stabilization (see Cray and Pollard 2015). Study sites on Herschel Island (Figure 1) included two stable upland tundra areas and five stabilized retrogressive thaw slumps representing three age classes: 10 years (two sites), 20 years (two sites), and 250 years (one site) since stabilization. For the 10- and 20-year-old stabilized thaw slumps, the year of stabilization was established by identifying the season in which there was

TABLE 1. Animal signs, by type, observed in 579 quadrats in undisturbed tundra and various age classes of stabilized thaw slumps on Herschel Island, Yukon, Canada, July 2011.

Animal sign type	Undisturbed, no. (%)		250-year-old stabilized, no. (%)		20-year-old stabilized, no. (%)		10-year-old stabilized, no. (%)	
	U1 (n = 72)	U2 (n = 72)	E (n = 244)		A (n = 44)	D (n = 23)	B (n = 100)	C (n = 24)
	U1 (n = 72)	U2 (n = 72)	E (n = 244)		A (n = 44)	D (n = 23)	B (n = 100)	C (n = 24)
Rodent nest material	7 (9.7)	5 (6.9)	5 (2.0)		0	0	0	0
Rodent runways	0	0	0		24 (54.5)	11 (47.8)	7 (7.0)	2 (8.3)
Rodent scat	0	1 (1.4)	4 (1.6)		0	0	0	0
Eider nest	0	0	1 (0.4)		0	0	0	0
Semipalmated Plover nest	0	0	0		2 (4.5)	2 (8.7)	0	0
Bird scat	2 (2.8)	0	7 (2.9)		7 (15.9)	3 (13.0)	19 (19.0)	13 (54.2)
Caribou scat	5 (6.9)	3 (4.2)	12 (4.9)		2 (4.5)	4 (17.4)	8 (8.0)	4 (16.7)
Muskox scat	3 (4.2)	1 (1.4)	1 (0.4)		0	0	1 (1.0)	0

no further headwall exposure or melt; the 250-year-old stabilized site was dated through sedimentological, geochemical, and accelerator mass spectrometry radiocarbon dating analyses by Lantuit *et al.* (2012).

Any recognizable scat was recorded; therefore, our observations likely consider droppings from multiple years. The number of quadrats sampled for each study site was scaled to 1% of the total area of each stabilized retrogressive thaw slump; 80% of these quadrats were spaced evenly along a transect perpendicular to the stabilized headwall, and the remaining 20% were distributed randomly within the stabilized area (for additional details see Cray and Pollard 2015). To maintain sampling uniformity, undisturbed areas were sampled with both transects and random quadrats in the same way as the other sites, where the median number of sample quadrats and the mean transect length were used for both undisturbed areas and the boundaries were assigned as a rectangle surrounding the transect (Figure 1).

Results

Rodent scat was observed only in the 250-year-old and undisturbed sites, whereas Caribou scat was observed in small amounts at every site (Table 1). Muskox scat was observed most frequently in the undisturbed sites and was not observed in the 20-year-old stabilized sites. Piles of dried grass and sedge material from rodent winter nests, 15–20 cm in diameter, likely representing complete nests (Krebs *et al.* 2012), were recorded at both the undisturbed and 250-year-old sites, although they were more frequent in undisturbed tundra. Nesting materials at the 250-year-old site were most frequently located near the headwall of the stabilized thaw slump. Surface grass tunnels, often referred to as runways (Krebs *et al.* 2012), were observed at the four 10- and 20-year-old stabilized slumps and were most common in the 20-year-old stabilized thaw slumps.

Although bird droppings were observed at every age class of tundra in this study, they were most frequent at the 10-year-old sites and decreased as site age increased. Of the five active bird nests we recorded, one was a Common Eider (*Somateria mollissima*) in the centre of the 250-year-old site and four were Semipalmated Plover (*Charadrius semipalmatus*) located in the approximate centre of the 20-year-old slump floors.

During the active period of a thaw slump and in the first few years following stabilization, animal tracks are readily observable in the soft mud of the slump floor (H.A.C. pers. obs.). Although not particularly useful for comparison between slump age classes, Muskox, Sandhill Crane (*Grus canadensis*), and Caribou tracks were also common in the slump floors of both 10- and 20-year-old sites.

Discussion

Based on our observations of animal signs, tundra birds and mammals appear to use stabilized slump surfaces and undisturbed tundra differently. Although our observations are limited to a small area and only one

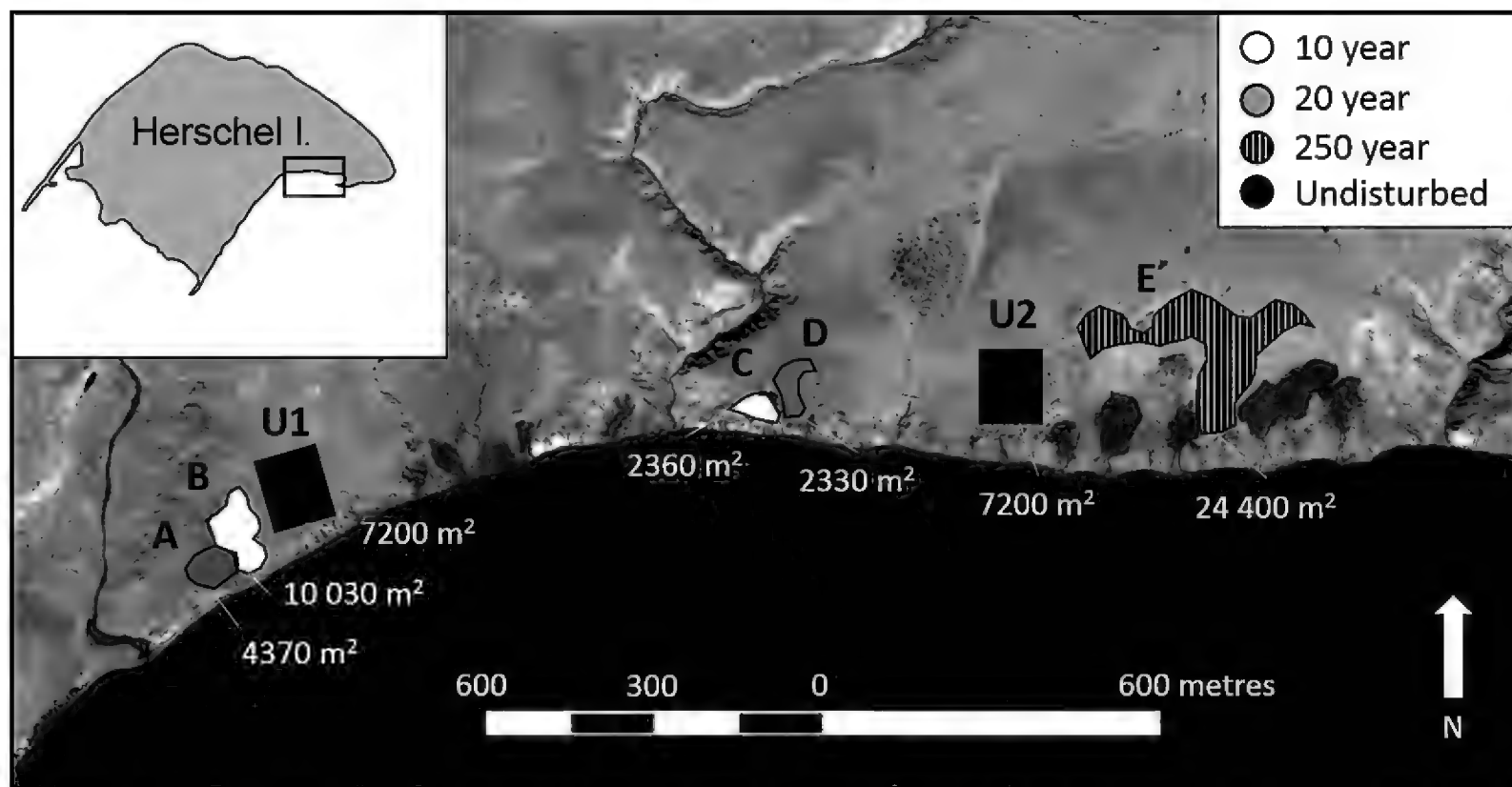


FIGURE 1. Locations of the seven study sites on Herschel Island, Yukon, Canada, including areas and age class of stabilized thaw slumps.

field season, these differences in rodent and bird habitat choice may be of interest to wildlife biologists for future study.

The occurrence of rodent burrows and winter nests near the headwall of the 250-year-old site could be because of the residual concave and steep morphology of long-stabilized thaw slumps, which leads to greater snow accumulation and, thus, thermal insulation for lemmings (Reid and Krebs 1996; Lantz *et al.* 2009; le Roux *et al.* 2011; Reid *et al.* 2011). As no rodent winter nesting materials were observed at the stabilized thaw slump sites, we suspect that the deposited dry, flat microtopography of the 10- and 20-year-old slumps is not preferred as winter nest sites. As all stabilized sites studied and many of the other more than 100 active and stabilized thaw slumps on Herschel Island are located in smooth or sloping uplands previously characterized by Arctic Willow/*Dryas*-vetch or cottongrass/moss vegetation type (Smith *et al.* 1989; Lantuit and Pollard 2008; Lantz and Kokelj 2008; Cray 2010, 2012), which is good year-round lemming habitat (Ale *et al.* 2011), the lack of burrows, rodent scat, or old nesting material at the 10- and 20-year-old sites suggests that an increase in the number and density of new thaw slumps may negatively impact rodent nesting habitat in the short term. However, rodent runways through the tall grasses were observed at all of the 10- and 20-year-old sites. In each area where there was a large percentage cover and height of grasses (i.e., 50% or more of the plant cover was >15 cm high), rodent runways were observed (Figure 2). Although no burrows or winter nests were found, rodents are likely making regular use of the 10- and 20-year-old sites as evidenced by the consistently trampled runways. Specific uses likely vary

by species and may include foraging for graminoids and seeds and collecting nesting material.

On Herschel Island, Collared Lemmings have been shown to select dry habitat dominated by Entire-leaved Mountain Avens (*Dryas integrifolia* Vahl; Ale *et al.* 2011) and to have a diet of mainly willow (*Salix* spp. L.), *D. integrifolia*, and Mountain Cranberry (*Vaccinium vitis-idaea* L.; Batzli and Jung 1980; Rodgers and Lewis 1986). Although *D. integrifolia* is most prevalent in the undisturbed tundra sites (present at 92% of sites, average cover 9%), it is also present at the 250-year-old site (present at 43% of sites, average cover 3%; Cray 2012), and various species of *Salix* are common at all sites studied (Cray 2012), particularly Arctic Willow (*Salix arctica* Pallas), which is highly preferred by Collared Lemmings (Rodgers and Lewis 1986).

Brown Lemmings may also benefit from foraging in the vegetation community that establishes following thaw slump stabilization. Although Brown Lemming has a pronounced preference for wet meadow habitat, compared with Tundra Vole and Collared Lemming, it is a habitat generalist (Batzli and Lesieutre 1995; Ale *et al.* 2011) whose diet is dominated by monocots, particularly sedges such as Water Sedge (*Carex aquatilis* Wahlenberg) and cottongrass (*Eriophorum* spp. L.) as well as mosses (Batzli and Jung 1980). Although too dry to support *C. aquatilis* and too recently disturbed to have established *Eriophorum*, the stabilized thaw slump sites do support both higher frequencies and a higher percentage cover of mosses than undisturbed tundra (Cray 2012), and the graminoid-rich communities of 10- and 20-year-old sites likely provide suitable forage for Brown Lemmings.

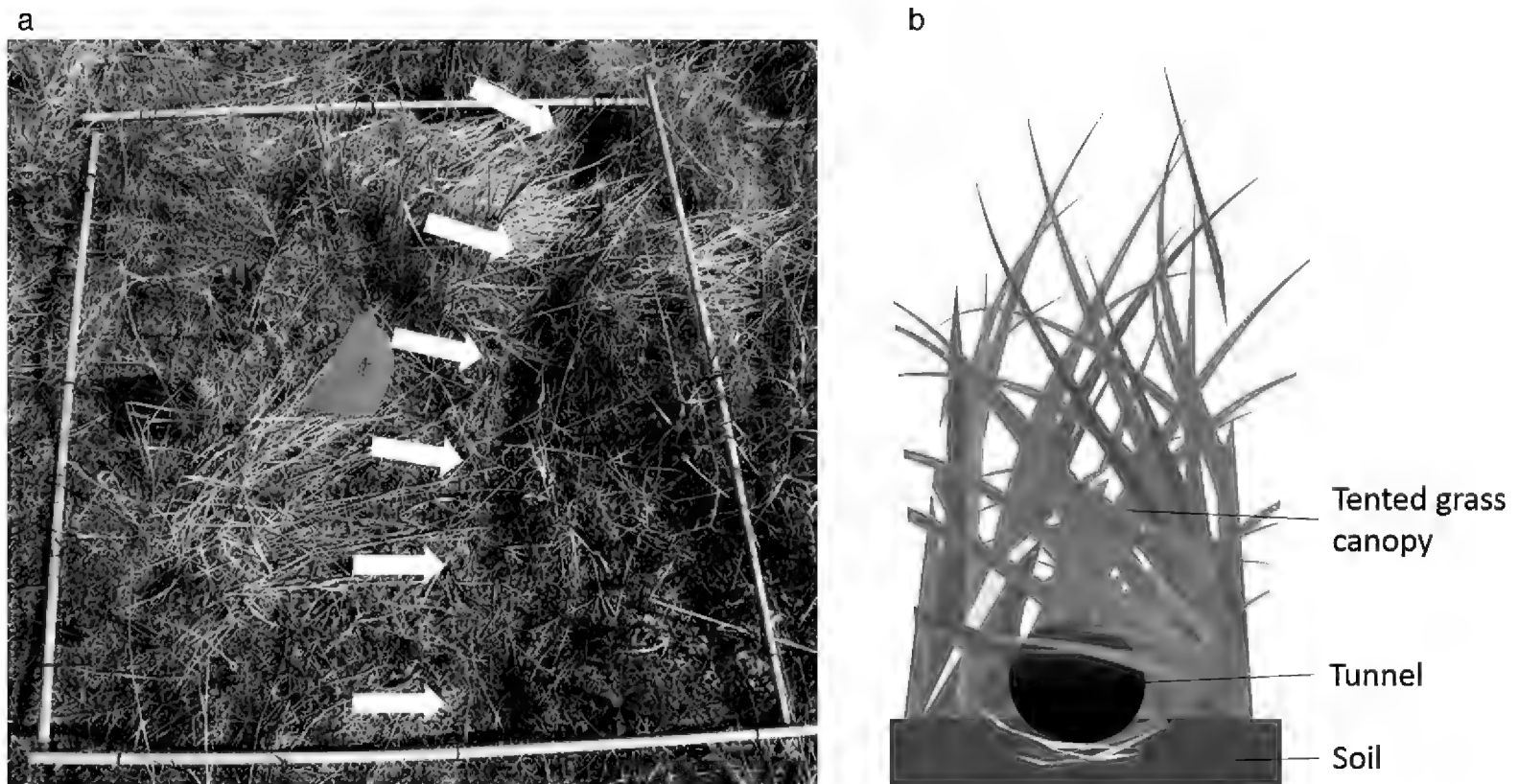


FIGURE 2. a. Photo of a quadrat in the 20-year-old stabilized thaw slump age class showing rodent surface grass tunnelling (runways). b. Lateral view of rodent runways through grass; note the tented canopy of grass obscuring the overhead view and the slight depression into the soil surface from repeated use. Photo and illustration: Heather Cray.

In contrast, although Tundra Voles have been shown to have a flexible diet including a variety of grasses, sedges, and forbs (e.g., lousewort [*Pedicularis* L.] typical of the stabilized thaw slumps (Batzli and Jung 1980; Cray and Pollard 2015), this species is rarely found outside Pauline Cove, 3 km away from the study sites (Krebs *et al.* 2012); on Herschel Island, it has been shown to prefer very wet habitat dominated by *Eriophorum* spp., *Carex* spp., and *Salix* spp. (Ale *et al.* 2011), more characteristic of undisturbed tundra. Therefore, it is unlikely that Tundra Voles are responsible for the animal sign found in stabilized slumps.

Tundra bird species also use stabilized thaw slump floors, certainly as nesting sites which were directly observed, and possibly as foraging areas as well. As the quadrat method we used is not ideal for observing bird nests and observations were made during only one field season, our nest observations likely underrepresent the true use of these stabilized surfaces by bird species. Also, as we did not identify bird scat to species, it is difficult to determine potential preferences of specific birds for certain cover types or vegetation communities. Because distinct vegetation communities were found to be associated with each age of stabilized thaw slump in the study by Cray and Pollard (2015), forage opportunities (arthropods, seeds) and nesting habitat would be expected to differ as well.

For Semipalmated Plover, which prefer to nest in an open area with little to no plant growth, disturbed patches may actually increase their breeding habitat, which otherwise mainly consists of beaches or open pebbled areas (Nguyen *et al.* 2003). Indeed, the Semipalmated Plover is among the few plovers whose numbers in-

creased between 1974 and 2009 and are currently stable (Andres *et al.* 2012), perhaps owing to its versatility in food choice or habitat expansion in the low Arctic as a result of disturbance (Nol and Blanken 2014).

Caribou scat was observed at every study site, suggesting that Caribou are at least travelling over if not grazing in every slump age class. Although the resilience of Caribou to vegetation change is contentious (Gunn and Skogland 1997; Callaghan *et al.* 1998; IPCC 2007), productivity of Caribou populations is strongly related to the quality and abundance of forage (Lenart *et al.* 2002) and the Porcupine Caribou Herd is known to forage extensively in the Tussock Grass (*Eriophorum vaginatum* L.) meadow community (cottongrass/moss) in the pre-calving and calving periods when *Eriophorum* heads are some of the first fresh vegetation available with significant biomass, cell solubles, nitrogen, and phosphorus (Russell *et al.* 1993). Although the cottongrass/moss vegetation type is generally considered stable (Smith *et al.* 1989), four of the five stabilized sites studied were located in this vegetation community, where thaw slumping initiated by coastal erosion progressed inland. Because *Eriophorum* does not recolonize stabilized thaw slumps even after 250 years (Cray and Pollard 2015), the significant increase in permafrost degradation expected with further climate change (Maxwell 1997) may affect the local availability of this vegetation type on Herschel Island and other upland areas prone to thaw slump activity, particularly areas adjacent to coastlines, lakes, and rivers.

Reductions in upland vegetation communities may also affect Muskox. The diet of Muskox consists mainly of graminoids, particularly sedges (e.g., *Carex* spp. and

Eriophorum spp.) and willows (*Salix* spp.; Ihl and Klein 2001; Larter and Nagy 2004), which are characteristic of undisturbed tundra sites on Herschel Island. Although stabilized thaw slumps are colonized by graminoid species within a few decades, the relative paucity of sedge and willow species at these sites (Cray and Pollard 2015) may explain the scarcity of Muskox scat observed at stabilized thaw slumps. With respect to winter forage, the increased snow accumulation within thaw slumps may also limit the availability of this food source for overwintering herds (Ihl and Klein 2001; Gustine *et al.* 2011).

Although our study indicates that mammals and birds appear to use recently stabilized thaw slumps, further investigation would be required to account for the complex biotic interactions and to predict consequences of the future, widespread permafrost disturbances expected with climate warming. As thaw slumps are expected to continue to increase in both area and number, the altered wildlife use associated with them present an interesting avenue for future research, particularly as the morphology, soil conditions, and vegetation community of stabilized slumps remain distinct from undisturbed tundra for over 250 years. To our knowledge, these observations are the first examples of birds and mammals using stabilized thaw slump habitat of different ages. We encourage all researchers working in these systems to record and report supplementary wildlife observations, as these observations play a useful role in building the larger wildlife and ecosystem knowledge base. Last, we suggest that long-term wildlife monitoring of stabilized thaw slumps would shed light on Arctic species' ability to adapt to permafrost disturbance and the resulting changes in vegetation cover.

Author Contributions

Writing – Original Draft: H.C.; Writing – Review & Editing: H.C. and W.P.; Conceptualization: H.C.; Investigation: H.C.; Methodology: H.C.; Formal Analysis: H.C.; Funding Acquisition: W.P. and H.C.

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Note

Clark's Nutcrackers (*Nucifraga columbiana*) caching Whitebark Pine (*Pinus albicaulis*) seeds in trees

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Abstract

On 17 September 2017, I observed two Clark's Nutcrackers (*Nucifraga columbiana*) from 8–10 m distance as they cached seeds in a stand of dead Whitebark Pines (*Pinus albicaulis*) at 2500 m elevation on Saint Mary Peak in the Bitterroot Mountains of Ravalli County, Montana. Over 5 minutes, the nutcrackers created 14 caches in seven different multi-trunk tree clusters in an area of about 50 m². All caches appeared to be single Whitebark Pine seeds, positioned 2–5 m (mostly 3–4 m) above ground in dead trees. Of the 14 caches, three were placed under loose pieces of bark on a trunk (one) or large limb (two), and the remaining 11 were in encrustations of American Wolf Lichen (*Letharia columbiana*) growing on branches of the dead trees. Nutcrackers are known to sometimes cache seeds above ground in trees during the late summer and autumn harvest of pine seeds, but usually not to the exclusion of other microsites. The ground at the Montana site was covered by 7–9 cm of fresh snow that fell the previous day, which may have encouraged the nutcrackers to place all of their seed caches above ground in trees.

Key words: American Wolf Lichen; caching behaviour; Clark's Nutcracker; *Letharia columbiana*; Montana; *Nucifraga columbiana*; *Pinus albicaulis*; tree caches; Whitebark Pine

Clark's Nutcracker (*Nucifraga columbiana*) is a major disperser of the large wingless seeds of Whitebark Pine (*Pinus albicaulis* Engelman), the only *Cembrae* pine of five globally that occurs in the mountains of western North America (Tomback and Linhart 1990). During late summer and fall, nutcrackers harvest Whitebark Pine seeds from the indehiscent cones and transport as many as 150 seeds in a single load up to 30 km from the source tree, where they are often cached in the ground for later retrieval and use as a high-energy food source during the following winter, spring, and summer (Tomback 1978, 1998, 2001; Lanner 1982, 1996; Dimmick 1993; Lorenz *et al.* 2011). Thousands of seeds are scatter-hoarded by individual nutcrackers each year, more than the nutcrackers need for survival and reproduction (Hutchins and Lanner 1982; Tomback 1982). Seeds are often cached in microsites where they have a good chance of germinating if they are not retrieved or predated (Tomback and Linhart 1990). Thus, through their caching activities the nutcrackers ensure the persistence of Whitebark Pine by planting the seeds across landscapes where the pines are most likely to persist or become established and eventually produce more seeds, which also results in the continued availability of a food resource generally relied on by nutcrackers throughout the year (Tomback 1978, 1982).

Clark's Nutcrackers typically cache Whitebark Pine seeds at bill-depth in the ground at the base of trees or rocks, in open terrain on slopes, under forest litter, in dense moss, and among tree roots, fallen logs, and annual plants (Tomback 1978, 1982; Hutchins and Lanner 1982; Dimmick 1993). Caching seeds above ground in trees is infrequently reported across the range of the nutcracker (Tomback 1978; Dimmick 1993), although

above-ground caching may be a regular behaviour of individual nutcrackers in some locations (Lorenz *et al.* 2011). Here I report opportunistic observations made of a pair of Clark's Nutcrackers caching Whitebark Pine seeds in dead Whitebark Pines. I provide details on the context of the caching activity and speculate about conditions that may encourage the choice of an arboreal microsite for caching seeds.

On 17 September 2017, while hiking to the summit of Saint Mary Peak in the Bitterroot Mountains, Ravalli County, Montana, I encountered two Clark's Nutcrackers at about 2500 m elevation caching seeds near the trail. The site (46.50569°N, 114.23336°W) was a stand of mature dead Whitebark Pine on the south-facing slopes of the peak. During 1055–1100 Mountain Daylight Time, I watched the nutcrackers from about 8–10 m with a 10× binocular as they performed their caching activities. I concentrated my attention on the closest bird, as both appeared to be behaving similarly. I saw the focal bird cache seeds 14 times, although the actual number of caches created was possibly double that amount during the 5 min of my observations, assuming both birds cached at the same rate.

All of the caches were located 2–5 m (mostly 3–4 m) above ground in seven different dead Whitebark Pines within an area of about 50 m², and all appeared to involve a single Whitebark Pine seed, based on the large size of the wingless seeds disgorged from the nutcracker's sublingual pouch to the tip of the bill and movement of the birds to new microsites after placing a single visible seed in a cache. Each bird paused and visually examined three or four microsites before caching a seed; at microsites where seeds were cached, the birds first probed two to five times with their bills. Three

of the 14 caches were placed under flakes of bark on a vertical trunk ($n = 1$) or large limb ($n = 2$) of a dead pine, and the other 11 were placed in encrustations of American Wolf Lichen (*Letharia columbiana* (Nutt.) J.W. Thomson) growing in patches on smaller branches of the dead trees (Figure 1). I did not see the nutcrackers cover any of the caches with extra bark or lichens. Although my sample of caches is small, the nutcrackers appeared at that time to prefer caching their seeds above ground (100% of 14 caches), rather than in the ground, and in lichens more so than other microsites on the trees (one-sample proportion test; Statistix® 8, Analytical Software, Tallahassee, Florida, USA: Z [corrected] = 1.87, $P = 0.061$). At no time during the encounter did I see either bird descend to the ground. My observations terminated when a third nutcracker flew downslope over the two caching birds and gave two or three “kraack” calls (“short-location calls”; see Tomback 1998), whereupon the two caching nutcrackers responded with “mew calls” and immediately flew away in the direction the third bird had travelled.

The amount of caching of Whitebark Pine seeds in trees by the Clark’s Nutcrackers I observed is high relative to most other reports of larger samples of caches made by nutcrackers, although still a small fraction of

the thousands of caches made each year. On the eastern slope of the Sierra Nevada Mountains in California, Tomback (1978, 1982) observed nutcrackers make 80 separate caches, only three (3.75%) of which were in trees (two-sample proportion test: Z [corrected] = 8.26, $P < 0.001$). Also in the Sierra Nevada, Dimmick (1993) observed the creation of 937 caches, of which only about 19 (2.0%) were placed above ground in erect Whitebark Pines or Lodgepole Pines (*Pinus contorta* Douglas ex Loudon; Z [corrected] = 19.15, $P < 0.001$). Of at least 157 nutcracker caches reported in northwestern Wyoming (Hutchins and Lanner 1982), none were placed in trees, which is the same pattern I observed for 95 nutcracker caches made elsewhere in Montana (Marks *et al.* 2016), all of which were buried in the ground at bill-depth.

Caching in the ground is also the typical pattern for the Eurasian Nutcracker (*Nucifraga caryocatactes*) in northern Japan when caching seeds of Japanese Stone Pine (*Pinus pumila* (Pall.) Regel; Saito 1983; Kajimoto *et al.* 1998; Hayashida 2003) and in northeastern China when caching seeds of Korean Stone Pine (*Pinus koraiensis* Siebold & Zucc.; Hutchins *et al.* 1996). Only ground caches were reported in the Japan studies, whereas tree caches accounted for 11 (8.4%) of 144



FIGURE 1. Typical American Wolf Lichen (*Letharia columbiana*) growth on a dead branch of Whitebark Pine (*Pinus albicaulis*) in which Clark’s Nutcrackers (*Nucifraga columbiana*) cached pine seeds in the Bitterroot Mountains, Ravalli County, Montana. The lichen patch is about 30 cm in length. Photo: P. Hendricks.

caches reported in the China study (Z [corrected] = 8.66, $P < 0.001$).

In sharp contrast with the earlier studies, Clark's Nutcrackers on the eastern slopes of the Cascade Range in Washington state regularly cached pine seeds in trees (Lorenz *et al.* 2011), and tree caches of Whitebark Pine seeds in particular made up 129 (64.8%) of 199 caches made by radio-telemetered birds. This is still less than the proportion of tree caches in my sample (Z [corrected] = 2.41, $P = 0.016$), but indicates that caching pine seeds in trees may be routine under some circumstances by some nutcracker populations. It is worth noting, however, that only 11 (5.5%) of the caches of Whitebark Pine seeds reported by Lorenz *et al.* (2011), both in trees and in the ground, were made in Whitebark Pine forest, unlike in Montana where all 14 caches I observed were in this forest type. Furthermore, most tree caches in the Cascades study, regardless of forest type, were in live trees among needle clusters, in lichen clumps within the foliage, and under pieces of bark. The microsites for the caches I noted in Montana fit in the last two categories, but all caches were in dead trees lacking any foliage other than arboreal lichens, unlike in Washington. Also, the lichens in which the Washington caches were placed were not identified or described, so it is unclear how similar or dissimilar the lichen cache microsites really are.

Lorenz *et al.* (2011) noted that nutcrackers caching seeds in live trees are less conspicuous than birds on the ground and may be overlooked unless they are telemetered, which could explain why they were observed more often caching Whitebark Pine and Ponderosa Pine (*Pinus ponderosa* Douglas ex Lawson & C. Lawson) seeds in trees than in studies lacking a telemetry component (Tomback 1978; Hutchins and Lanner 1982). Lorenz *et al.* (2011) also suggested that the amount and duration of winter snowpack could influence the magnitude of ground caching, because snow cover inhibits future access to ground caches (Tomback 1978) but not caches in trees. Earlier studies reporting caching behaviour were conducted at the lower latitudes of California (Tomback 1978, 1982) and Wyoming (Hutchins and Lanner 1982) in drier forest types with less winter snowpack than the Cascades, possibly favouring a greater amount of ground caching at those locations.

The Montana nutcrackers I encountered were quite visible in the dead pines, which lacked any foliage other than lichens, and it was easy to observe them caching seeds. Nevertheless, limited data from Montana (Marks *et al.* 2016) indicate that ground caching by nutcrackers may be routine in Whitebark Pine forest during the harvest of pine seeds, as it is in California (Tomback 1978, 1982; Dimmick 1993) and Wyoming (Hutchins and Lanner 1982). Here, factors in addition to future cache accessibility during winter and spring may affect choice of cache microsites. In particular, access to an array of potential microsites at the time of cache cre-

ation could influence the incidence of caching pine seeds in trees. When I made my observations, the ground at the Montana site was covered with 7–9 cm of soft snow, which had fallen the previous day. The two nutcrackers I encountered showed no inclination to cache pine seeds in the ground, which could have been purely a response to the presence of an ephemeral snow cover that interfered with location of potential cache microsites on the ground rather than any general preference by the birds to cache seeds in trees. Frequent use of lichens as a microsite for tree caches may have been a result of lichen abundance in the absence of other foliage.

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Revisiting the hypothesis of sex-biased turtle road mortality

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Abstract

Road mortality poses a major threat to turtle populations. Several studies have suggested that the terrestrial movements associated with nesting increase this risk for females. The Ontario Turtle Conservation Centre (OTCC) is home to the Kawartha Turtle Trauma Centre, which admits 900 or more turtles a year, with road injuries the primary cause of admission. We tested the hypothesis that road mortality in turtles is female-biased using data from injured Midland Painted Turtles (*Chrysemys picta marginata*), Snapping Turtles (*Chelydra serpentina*), Blanding's Turtles (*Emydoidea blandingii*), and Northern Map Turtles (*Graptemys geographica*) collected over about 126 000 km² and admitted to OTCC's hospital from January 2013 to October 2017. There was no difference in the number of male and female admissions of Midland Painted, Blanding's, or Snapping Turtles ($P > 0.05$); however, more female Northern Map Turtles than males were admitted ($P < 0.001$). Admission of female turtles peaked in June during the nesting season, but male admissions were more evenly distributed throughout the season. Our admissions data provide a temporally unbiased and geographically broad snapshot of turtle–vehicle interactions that can directly inform conservation and management policies. Although our data are not equivalent to mortality rates, these results demonstrate that vehicle strikes can have a substantial impact on both female and male turtles.

Key words: Midland Painted Turtle; Snapping Turtle; Blanding's Turtle; Northern Map Turtle; *Chelydra serpentina*; *Chrysemys picta*; *Emydoidea blandingii*; *Graptemys geographica*; Ontario; road ecology; road mortality; sex-biased dispersal; sex ratio; wildlife rehabilitation

Introduction

Roads have been called the “sleeping giant” of conservation biology (Forman and Alexander 1998) because of their pervasive negative impact on biodiversity and habitat connectivity. The effects of roads include habitat fragmentation, barriers to movement, genetic isolation of population fragments, and direct mortality from vehicle–wildlife collisions (Strasbourg 2006; van der Ree *et al.* 2011; Beebee 2013). Smaller, slower wildlife species may be more susceptible to vehicle strikes because they take more time to cross a road, increasing the probability of interaction with a vehicle, and may not use flight as a predator response, further increasing the likelihood of vehicle strikes (Fahrig and Rytwinski 2009). Turtles are particularly vulnerable to mortality caused by vehicle strikes because their long lifespan and slow population growth rates magnify the population-level impact of small increases in adult mortality (Congdon *et al.* 1993; Gibbs and Steen 2005; Crawford *et al.* 2014; Rytwinski and Fahrig 2015).

Several studies have tested the hypothesis that female turtles are at higher risk of road mortality during the nesting season because overland movements required to find a suitable nest site may increase females' probability of contact with roads (Steen and Gibbs 2004; Aresco 2005; Gibbs and Steen 2005; Steen *et al.* 2006; Patrick and Gibbs 2010; Dorland *et al.* 2014). In addition,

females that nest on the shoulder of paved roads, even those that have repeatedly nested at the same area, can spend considerable amounts of time searching the road, whereas males typically cross the road and do not show this nest-searching behaviour (R. Brooks pers. comm. 11 May 2018). If road mortality is female-biased, then the adult sex ratios of turtle populations should gradually become male-biased (Steen and Gibbs 2004; Gibbs and Steen 2005; Steen *et al.* 2006; Patrick and Gibbs 2010; Dupuis-Désormeaux *et al.* 2017).

Road mortality studies often do not report the sex of the turtles (e.g., Ashley and Robinson 1996; Gunson *et al.* 2014; Baxter-Gilbert *et al.* 2015; Coquette and Valiant 2016; Dupuis-Désormeaux *et al.* 2017) or only report the sex of a limited sample (Haxton 2000). In addition, some road mortality surveys are carried out for a limited portion of the active season (e.g., Haxton 2000) or for a limited number of days throughout the season (e.g., Cureton and Deaton 2012). A temporally unbiased dataset of road mortality occurrences in male and female turtles is required to test directly the hypothesis of sex-biased road mortality occurrences in turtles at the landscape scale.

The Ontario Turtle Conservation Centre (OTCC; <https://ontarioturtle.ca/>) is home to Canada's only dedicated turtle rehabilitation centre. The OTCC admits turtles injured in a variety of ways, but the vast majority

of admissions (80–95%, depending on the species) represent turtles injured on roads across southern Ontario. Southern Ontario contains 92% of Ontario’s human population and some of the highest concentrations of roads on the planet with a road located, on average, every 1.5 km (Gunson 2010; Laurance *et al.* 2014). Admissions to the OTCC include all eight species of turtles native to Ontario, including the globally endangered Spotted Turtle (*Clemmys guttata*; van Dijk 2011) and Blanding’s Turtle (*Emydoidea blandingii*; van Dijk and Rhodin 2011). All Ontario species except Spiny Softshell (*Apalone spinifera*) have been admitted with vehicle-related injuries.

Admissions to the OTCC have increased steadily since 2010 (Figure 1), in part because of increased public participation following intensive public education initiatives. The OTCC admissions dataset provides an opportunity to test the hypothesis of sex-biased road effects on a large, temporally unbiased and geographically broad sample of turtles struck by vehicles across an area of approximately 126 000 km². We used OTCC data to test the hypothesis that interactions with vehicles affect more female turtles than males, predicting that if more females than males are struck by vehicles in our intake area, then counts of turtles admitted to the OTCC would also be significantly female biased.

Methods

Located in Peterborough, Ontario (44.336776°N, 78.348319°W), the OTCC is the home of the Kawartha

Turtle Trauma Centre (KTTC), which receives cases from across southern Ontario and occasionally from southern Quebec. Turtles are brought to the OTCC by members of the public and field biologists or transferred from other wildlife rehabilitation centres when complex veterinary care is required. Admissions include all species of turtles native to Ontario, but the majority are Midland Painted Turtles (*Chrysemys picta marginata*), Snapping Turtles (*Chelydra serpentina*), and Blanding’s Turtles. During admission, OTCC staff record each turtle’s species, sex, size (carapace length and width), and age class (hatchling, juvenile, or adult), as well as the reason for admission and the collection location. Admissions to the hospital take place all year round; however, most occur from mid-April to late October, during the active season of turtles in southern Ontario.

Vehicle strikes typically cause life-threatening injuries to turtles (Figure 2), and medical records from the centre confirm that successful outcomes and rehabilitation of turtles hit by vehicles depend on rapid veterinary treatment. Therefore, these turtles would have died in the absence of treatment, and their admissions data are an appropriate proxy for vehicle-related mortalities.

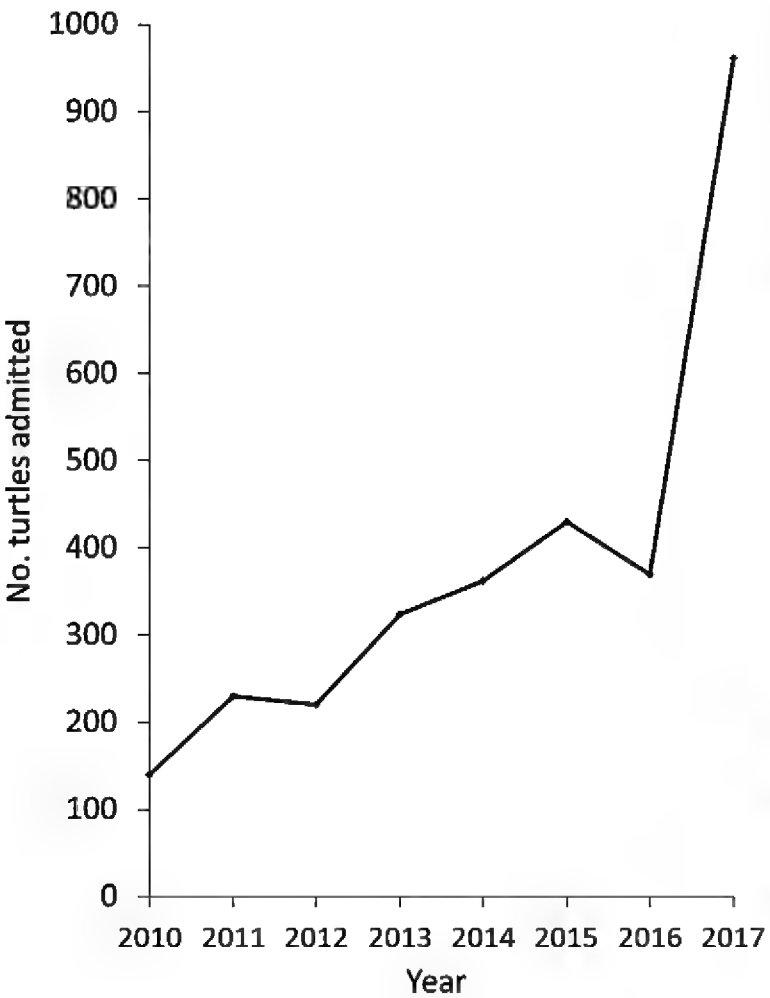


FIGURE 1. Increase in admissions to the turtle hospital at the Ontario Turtle Conservation Centre since 2010.

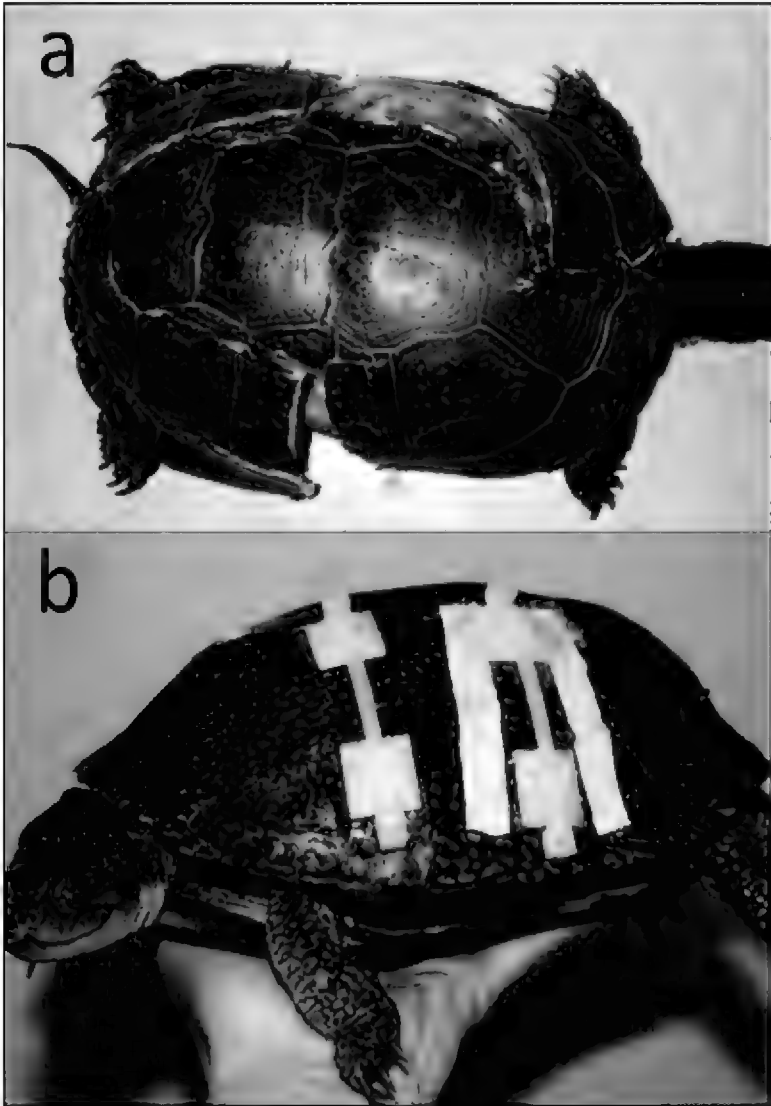


FIGURE 2. a. Injuries from vehicle strikes are typically life-threatening, as in this Blanding’s Turtle (*Emydoidea blandingii*), but rapid surgical attention often allows turtles to recover. b. Blanding’s Turtle that was successfully rehabilitated and released back into the wild. Photos: S. Carstairs.

Successfully rehabilitated turtles are released back into the wild near their initial collection location.

We used OTCC admissions data from January 2013 to October 2017 to test whether vehicle strikes on turtles occur more frequently in one sex than the other. We removed the records of turtles that were admitted for other reasons and limited our data set to those hit by a vehicle. We tested for significant deviations from an unbiased sex ratio in the admissions data by performing a nonparametric binomial two-sided test based on a one-sample binomial distribution (Wilson and Hardy 2002) with the untested assumption that the populations of turtles in the study area were also not sex biased. All statistics were performed in Microsoft Excel (Microsoft Corporation, Redmond, Washington, USA), and we considered results significant at $\alpha = 0.05$. Loca-

tion data were mapped using ArcMap 10.1 (ESRI, Redlands, California, USA).

Results

During the study period, the OTCC admitted 2355 turtles, of which 2020 were admitted due to vehicle strikes (Figure 3). Of these, 1722 were mature individuals and were sexed during the admission process; Wood Turtle (*Glyptemys insculpta*) vehicle strikes are not shown due to locational sensitivity. Most vehicle strikes involved Midland Painted Turtles (62%), followed by Snapping Turtles (29%), and Blanding’s Turtles (6.5%; Table 1). Approximately half (51%) of turtles admitted because of vehicle strikes were female, and admissions of female Midland Painted Turtles, Snapping Turtles, and Blanding’s Turtles peaked in

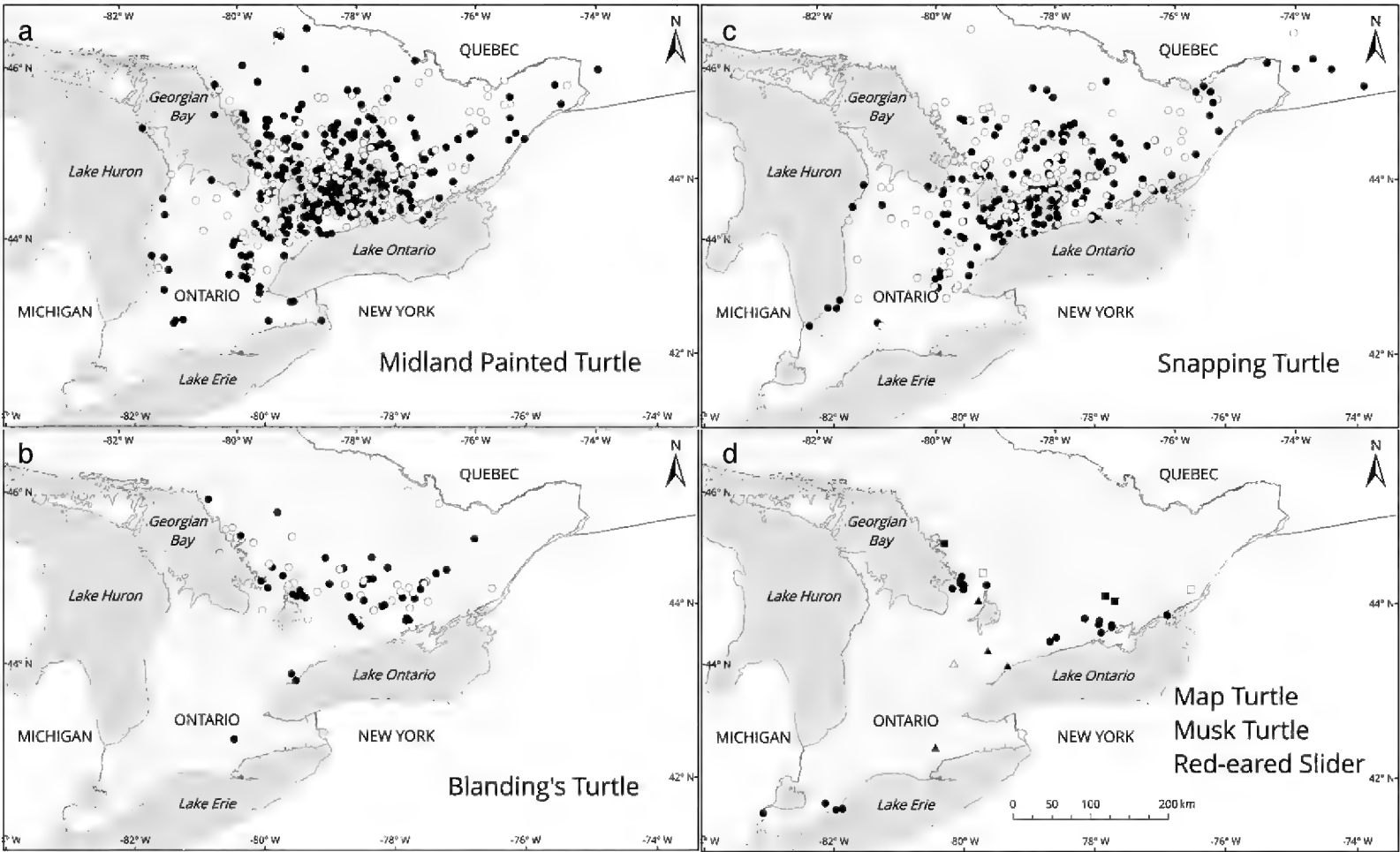


FIGURE 3. Locations of vehicle strikes of adult turtles admitted to the Ontario Turtle Conservation Centre, 2013–2017. Open symbols = males; black-filled symbols = females. In the lower right panel (d), circles indicate Northern Map Turtles (*Graptemys geographica*); squares indicate Eastern Musk Turtles (*Sternotherus odoratus*); and triangles indicate Red-eared Sliders (*Trachemys scripta elegans*).

TABLE 1. Species and sex distribution for 1722 adult turtles admitted to the Ontario Turtle Conservation Centre because of vehicular collisions from 2013 to 2017.

Species	Females	Males	Proportion of males	P*
Painted Turtle (<i>Chrysemys picta</i>)	541	532	0.496	0.404
Snapping Turtle (<i>Chelydra serpentina</i>)	249	254	0.505	0.606
Blanding’s Turtle (<i>Emydoidea blandingii</i>)	63	49	0.438	0.120
Northern Map Turtle (<i>Graptemys geographica</i>)	32	2	0.059	<0.001†
Total	885	837	0.486	0.129

*Indicates cumulative probability that the observed sex ratio reflects an unbiased binomial distribution centred around 0.5.
†Sample was significantly biased toward one sex or the other ($\alpha = 0.05$).

June, concurrent with the nesting season for these species. Admissions of male turtles showed multiple clusters extending from early spring to late fall (Figure 4). Turtles were admitted for care following vehicle strikes as early as 13 March (2013), as late as 25 October (2017).

A binomial test showed that admissions of male and female turtles struck by vehicles, when combined over all five years, were not statistically different for Midland Painted Turtles ($P = 0.404$), Snapping Turtles ($P = 0.660$), or Blanding’s Turtles ($P = 0.110$; Table 1). Admissions of Northern Map Turtles (*Graptemys geographica*) were significantly female biased ($P < 0.001$), but map turtles made up only 2% of all vehicle-related admissions.

Discussion

Our temporally unbiased, 5-year admissions dataset from the OTCC does not support the hypothesis of sex-biased road mortality in Midland Painted, Snapping, or Blanding’s Turtles, but suggests that roads may have a greater impact on female Northern Map Turtles

than on males. The OTCC admits turtles year round, enabling continuous collection of road mortality data over five years and accurate sexing of each turtle admitted. Our road mortality data are count data, like those of most other road ecology studies, and cannot be converted to mortality rates because robust demographic data are available for only a few well-studied turtle populations. However, the even distribution of road mortality occurrences among males and females of the most commonly hit species in our dataset suggests that the impact of roads on turtles is more evenly shared between the two sexes than previous studies have suggested.

Painted, Snapping, and Blanding’s turtles frequently move over land to find mates, to access resources such as foraging or overwintering sites, or to find a suitable nest site (Pettit *et al.* 1995; Tuberville *et al.* 1996; Ernst and Lovich 2009). These activities bring both males and females of these three species into contact with roads, as reflected in our data. Nesting season is clearly associated with increased risk of road injury for female turtles in Ontario. However, our results also provide empirical support to a recent modelling approach (Beaudry

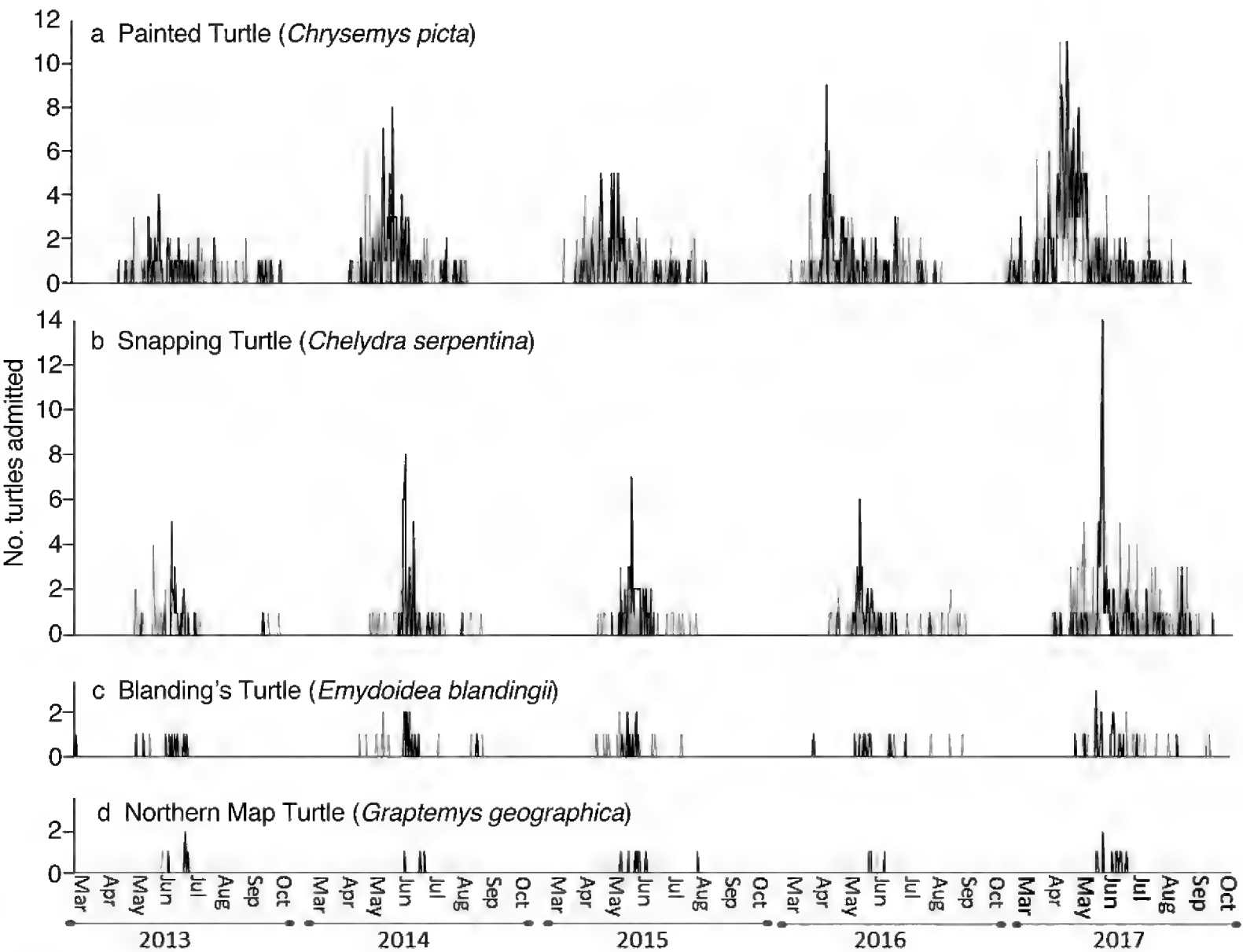


FIGURE 4. Admissions of male and female turtles struck by vehicles ($n = 1722$). Numbers are similar for male and female a. Midland Painted (*Chrysemys picta*), b. Snapping (*Chelydra serpentina*), and c. Blanding’s Turtles (*Emydoidea blandingii*). Admissions of female turtles (black lines) peaked during the nesting season, while admissions of males (grey lines) were more evenly spread through the season. d. Northern Map Turtle (*Graptemys geographica*) females were more likely to be admitted than males. No admissions caused by vehicle strikes occurred from November to February.

et al. 2010) that suggests that male mortality is similar to female mortality when the entire active season of mid-April to the end of October is considered. Beaudry *et al.* (2010) found that male and female Blanding's Turtles had similarly long movement patterns and were both similarly exposed to road mortality. However, males moved more than females, before and after nesting season.

Although our sample of Northern Map Turtles was small ($n = 34$), it was heavily biased toward females (94%). The behaviour of Northern Map Turtles is consistent with this observation: male Northern Map Turtles are almost exclusively aquatic, whereas females emerge rarely, usually only to find a suitable nest site (Ernst and Lovich 2009).

Survivorship in female turtles has been a focus of turtle ecologists and conservation biologists for good reason; it has an extremely high impact on the growth rates of turtle populations (Congdon *et al.* 1993; Heppell *et al.* 1996; Heppell 1998; Mitrus 2005; Enneson and Litzgus 2008). Therefore, maximizing female survivorship is considered a key component of effective turtle conservation. Nevertheless, reproductive males and females are required to sustain a viable turtle population, and conservation programs should ensure adequate survival rates in both sexes. Most methods used to mitigate road impacts on turtles (ecopassages, drift fencing, etc.) probably provide equal protection to both sexes. Road closures during the nesting season may adequately protect nesting female turtles but fail to protect males and females moving overland during the rest of the active season.

One tool used to recover threatened turtle populations is "headstarting", in which eggs are hatched in artificial conditions that maximize success and eliminate nest depredation. Hatchlings are often also reared for some amount of time before release, which may reduce the risk of early juvenile mortality (e.g., Iverson 1990; Haskell 1996; Bennett *et al.* 2017). In species with temperature-dependent sex determination, incubation conditions can be controlled to produce a predetermined sex ratio in hatchlings. Setting aside the many factors that can prevent recruitment of headstarted or wild-hatched juveniles to a turtle population, our data add evidence to suggest that headstarting projects or other attempts to augment populations should consider both sexes and not focus solely on females. The fact that females spend more time on roads, and yet males are struck in equal numbers, also illustrates the high impact of roads on the male population.

Converting mortality count data, such as those presented here, to mortality rates for male and female turtles in a population and, thus, inferring and projecting population level impacts requires knowledge of the sex ratio of the underlying population—a major limitation of our study and of many others. Accurately estimating population sex ratios requires substantial survey effort, and some survey methods do not have equal detection

rates for both sexes. For example, hoop traps may capture male-biased samples of Painted Turtle populations (Ream and Ream 1966), while surveys of turtle nesting sites are necessarily female-biased. Furthermore, counts of road mortality for long-lived animals, such as turtles, do not accurately represent demographic trends (Rytwinski and Fahrig 2015), and unequal male and female road mortality rates could cause yearly fluctuations in the population's sex ratio as the population nears extinction.

The underlying reasons for the discrepancy between the equal sex ratio in road injuries that we found and the increasing male-biased population sex ratios correlated with higher road densities found in numerous other studies (e.g., Marchand and Litvaitis 2004; Steen and Gibbs 2004; Aresco 2005; Gibbs and Steen 2005; Steen *et al.* 2006; Patrick and Gibbs 2010) remain uncertain. We urge road ecologists to remain critical of the underlying assumptions in the interpretation of mortality counts, and we urge turtle researchers to be cautious of assumptions that could inadvertently prioritize protection of one sex over the other.

The morbidity and mortality of reptiles admitted to wildlife care facilities in North America has been described previously (Hartup 1996; Brown and Sleeman 2002; Rivas *et al.* 2014), but these studies focus on the veterinary medicine aspects of rehabilitation. Our study demonstrates how admission data from a wildlife rehabilitation centre can be used to address broader questions in conservation and draw inferences about threats to wild populations. Perhaps a future approach to these and new data would be to examine the sex ratio variation with location and to compare traffic, road density, or population composition. There are numerous possibilities, but our large sample at a landscape level is unique and could be explored further. Turtles are long-lived and slow to mature and the survival rate of eggs and hatchlings is low. Turtle populations cannot recover quickly from increased adult mortality (Brooks *et al.* 1991). Conversely, offsetting increased mortality can have a relatively large impact on demographic rates, such that rehabilitation and release of injured turtles may have a population-level effect.

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Book Reviews

Book Review Editor's Note: *The Canadian Field-Naturalist* is a peer-reviewed scientific journal publishing papers on ecology, behaviour, taxonomy, conservation, and other topics relevant to Canadian natural history. In line with this mandate, we review books with a Canadian connection, including those on any species (native or non-native) that inhabits Canada, as well as books covering topics of global relevance, including climate change, biodiversity, species extinction, habitat loss, evolution, and field research experiences.

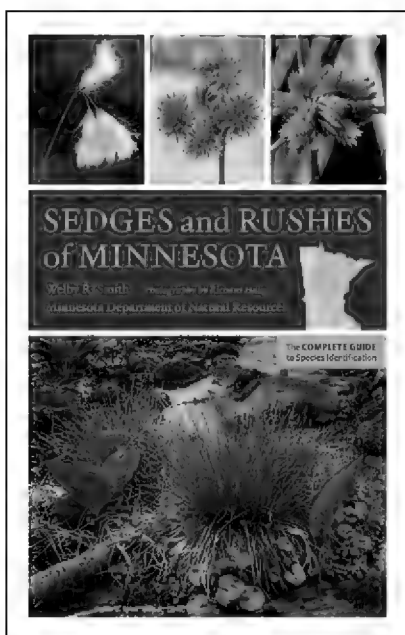
Currency Codes: CAD Canadian Dollars, USD US Dollars, EUR Euros, AUD Australian Dollars, GBP British Pound.

BOTANY

Sedges and Rushes of Minnesota: The Complete Guide to Species Identification

By Welby R. Smith. Photography by Richard Haug. 2018. University of Minnesota Press. 696 pages, 1100 colour plates, and 248 maps, 39.95 USD, Paper.

Over the past decade or so, several states or regions in North America (e.g., Maine, New England, Pacific Northwest, Wisconsin) have had guides published on the identification of the sedges (Cyperaceae) found within their boundaries. This guide to the sedges and rushes (Juncaceae) of Minnesota is one of the most recent additions to this



list, and reflects the increasing interest among field botanists in understanding and being able to identify members of this large, diverse, and ecologically important group of graminoids. The inclusion of the rush family in the Minnesota guide is a welcome addition that the other guides mentioned above do not cover.

The book begins with basic information on sedges and rushes, and explains that the main purpose of the book is to provide a tool for field botanists who want or need to identify these plants within their study areas. Thus, the book is aimed at anyone who might be conducting biological inventories, whether professional or amateur. The author has made a concerted effort to use non-technical terms whenever possible and, when not possible, has provided simple explanations of the technical terms. The introductory sections of the book also include acknowledgements of those who assisted with production, including the primary photographer, Richard Haug, who has done a great job of representing the important features of each species with his images. These sections also contain some basic information, including maps, on the ecology of the state as it relates to

plant distributions (major substrate types, historical vegetation types, and vegetation zones).

The main contents of this book are the sedge and rush identification aids, including keys, photographs, descriptions, and range maps. The first key enables identification of the genera of sedges and rushes in Minnesota. From there, all of the genera are arranged alphabetically, and within genera (and within sections in the large genus *Carex*) species are also arranged alphabetically. This can mean that similar-looking species within related sections in the genus *Carex* may not be situated close to each other within the book, but that should not be a major impediment for most users. The species concepts used in the book reflect the most current thinking regarding the taxonomy of these plants, in a few cases being even more current than that found in *The Flora of North America* treatments for these families (Brooks and Clemants 2000; Ball *et al.* 2002).

The treatment of each genus begins with a description based on the species found in Minnesota, along with basic information on the diversity of the genus worldwide, in North America, and in the state. Accompanying photographs focus on the most important and characteristic features of the genus that will aid in identification. Next comes a key to the species in the state, followed by species accounts. Each species has two pages dedicated to it: the first is a full page of descriptions, notes on how to differentiate the species from similar ones, and habitat notes, along with a distribution map; the facing page contains images of important identification features and characteristic habitat. The descriptions, notes, and images are all well done, focusing on the important features required for identification of the species.

In the case of the genus *Carex*, however, which is by far the largest genus covered in the book, additional text is devoted to describing the unique features and architecture of the inflorescence, again accompanied by excellent annotated photographs. This is followed by

a key to the sections within the genus, and then each section is covered alphabetically in the same way that genera are treated elsewhere in the book. Each section contains a key to the species, along with representative photographs, and then the species are treated in alphabetical order within the section.

This is an excellent guide to the sedges and rushes of Minnesota, and will be applicable to much of the Midwest and adjacent portions of Manitoba and western Ontario. The keys are workable, the descriptions are good and easily understood because of the plain language explanations that are provided where the author deemed that they were needed, and the photographs are excellent. If one considers that the book is written with Minnesota in mind, rather than the globe, then the content is accurate and thorough. (However, if one were to look at the Cyperaceae with a global view, then there are other genera with perigynia, not just *Carex*; p. 14.) In a few cases, additional characters could have been included to make recognition of a species even easier (e.g., the glaucous nature of the foliage in *Carex canescens*, the gynecandrous terminal spike of *C. gracillima* relative to the staminate terminal spike of *C. arctata*, glossy appearance of the perigynia in *C. pallescens*), but the keys, descriptions, and photographs should virtually always lead the user to the correct identity. I do have a few minor quibbles, such as slight discrepancies in colour descriptions, particularly of the achenes, where the photographs sometimes illustrate colours not reflected in the descriptions (due to degree of maturation of the achenes); however, these will rarely if ever affect the usefulness of the book.

There are very few typographical or grammatical errors, and my sense is that the book has been produced with a great amount of care and attention to detail.

There is only one aspect of the organization of the book that bothers me: the lack of separation between the two families in the main body of the text. There are only two genera of Juncaceae in the flora (*Juncus*, *Luzula*), and the flower structure of the family is so different from that of Cyperaceae. Therefore, it would have been a simple matter to separate, rather than intersperse, the two families, without losing anything in the process. Rather, in my opinion, something would have been gained, in terms of the user's understanding of the differences between the two families.

Overall, this book provides an excellent, user-friendly guide to the sedges and rushes of Minnesota. I recommend it highly to all field biologists involved in botanical inventories in the central part of the continent, and to students of these two families in general.

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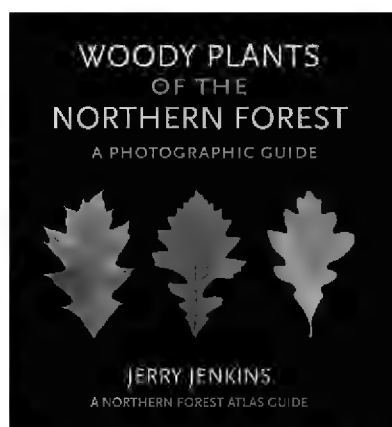
Woody Plants of the Northern Forest – A Photographic Guide

By Jerry Jenkins. 2018. Comstock Publishing Associates – An Imprint of Cornell University Press. 64 pages, 25.50 USD, Paper.

Woody Plants of the Northern Forest – Quick Guide

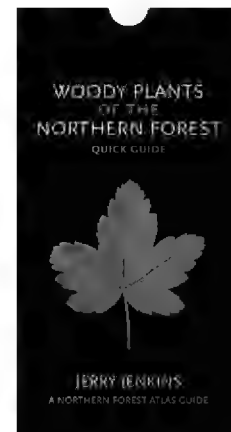
By Jerry Jenkins. 2018. Comstock Publishing Associates – An Imprint of Cornell University Press. Foldout Chart, 11.95 USD, Paper.

The Northern Forest Atlas (NFA) and its principle director, Jerry Jenkins, have produced a beautiful, easy-to-use, and innovative identification book, the *Woody Plants of the Northern Forest – A Photographic Guide*. The accompanying *Quick Guide* and online material help to fulfill the aims of the NFA in producing ground-breaking resources, targetted at naturalists and ecologists, to aid in fostering conservation and stewardship of the Northern Forest Region. Lying between the oak forests of the eastern United States and the boreal forests of eastern Canada, the Northern Forest Region is one of the largest, most diverse, and



contiguous of temperate forests and, as the author stresses, is of utmost ecological importance. With a focus on rapid identification, based on multi-image composite photos, these resources provide an accessible, modern approach to field guides.

The *Photographic Guide* (its 10 × 11" size is ideal for backpack or coffee table, but not pocket) is intended to help rapidly identify twigs and leaves of woody plants through a series of quick photographic keys and more systematic sections. Nineteen 'quick guides' (not to be confused with the *Quick Guide* folding charts) at the front of the book help separate groups with distinctive features, for example thorns or lobed leaves. Not all of the 235 species photographed possess distinctive fea-



tures and therefore not all appear in one of the quick guides. The rest of the book is divided into systematic sections arranged to rapidly arrive at species identification. These systematic sections divide the species into five groups: evergreens, opposite buds, alternate buds, opposite leaves, and alternate leaves. Species within each group are arranged alphabetically by family and genus.

The *Photographic Guide* is very user-friendly: its content is divided in a straightforward and accessible manner that lends itself to rapid orientation, in contrast to the frequently overwhelming nature of many woody plant identification guides. Similar species are easily comparable, with brief annotations to help guide towards identification suggestions; in fact, the author stresses that the guide serves to “suggest and eliminate, but not confirm” (p. 1). It is also noted in the introduction that not every woody plant encountered can be identified by leaves or twigs alone, with some groups requiring bark and sometimes flowers. This brings me to one of my only criticisms of the *Photographic Guide*: why not include photographs of bark or flowers for these trickier groups? In truth, this information is available via the Northern Forest Atlas website (<http://northernforestatlas.org/>), but I don’t see why it could not be included here, unless the aim of basing these guides solely on leaves and twigs overrides the need to confirm a positive species identification for all specimens. There is definitely merit in stimulating the questioning process and to encourage utilizing a range of available resources.

The photographs themselves are integral to this modern field guide approach—with each studio photo taken from multi-image composites. Stacking technology and software produce a single image by combining the sharpest points from each of a series of frames. This results in beautifully fine detailed images, rich in depth and with even the finest twig bud details appearing crystal-clear. This technique also results in variation and imperfections in many of the specimens, with the author describing some to be “meaningful” and some “accidental” (p. 1)—the user is cautioned in the introduction that this variation mirrors what will be encountered in the field. The author goes on to assign the user

the task of determining where “casual variation ends and species lines begin” (p. 1), implying the importance of individual exploration and continued learning. A visual glossary at the front of the *Guide*, and a gallery of photos of full tree photos at the end, round out this resource nicely. Although the gallery could easily have been expanded to include shrubs, it does a succinct job of identifying the tree species for which a profile or silhouette is a useful and viable approach to identification.

The companion *Quick Guide* folding charts provide a more pocket-friendly version of the *Photographic Guide*. The package comprises two charts, “winter” and “summer”, each printed on durable, water-resistant paper. The winter chart focusses on the twigs and buds, whilst the summer chart concentrates on identification mostly from leaves, although much of the “evergreen” sections are duplicated. This results in highly practical field tools that are tailored to specific field seasons, and therefore aid in speeding up the identification process through making these resources as efficient as possible for the active field naturalist.

The affordable price tag for the *Quick Guide* and the *Photographic Guide* make either a welcome addition to any naturalist’s library. The unique arrangement of the *Photographic Guide* and the versatility of the *Quick Guide* result in each having its functional role, and helps advocate for those who wish to invest in both resources. Online users are able to access a library of high-resolution images ranging from aerial to near microscopic photos, in addition to downloadable charts and other products. A forthcoming digital atlas and new guides to sedges of the Northern Forest are signs of more ground-breaking work in the pipeline. The reaffirmation from Jerry Jenkins across all of these physical and digital resources is that the purpose of the Northern Forest Atlas Project is to document the beauty and diversity of these vast forests, whilst providing tools for the next generation of conservationists looking to study and protect them. These two offerings on the *Woody Plants of the Northern Forest* certainly do an innovative job in meeting these goals.

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ORNITHOLOGY

The Birds of Vancouver Island’s West Coast

By Adrian Dorst. 2018. UBC Press, On Point Press. 544 pages and 140 black and white photographs/maps, 39.95 CAD, Cloth.

Adrian Dorst’s new book on the birds of the wild west coast of Vancouver Island is an engagingly-written, straightforward, and thorough account of the region’s avifauna. The author has lived in Tofino for over four decades and has spent all those years “recording the comings and goings of birds” (p. 13) in his wilderness neighbour-



hood. He knows the region intimately—the rich pelagic waters, the wave-scoured rocks, the long beaches that stretch off into the mist, the quiet inlets, the great forests, and the rugged, almost inaccessible mountains. He also loves this area, and this love comes through on every page.

This is not a field guide, but rather a detailed account of the occurrence and ecology of each of the 360 bird species known from the region. In addition to his extensive personal experience, the author has gathered information from a wide variety of sources, including birding websites, the scientific literature (355 references are cited at the back of the book), the four volumes

of *The Birds of British Columbia* (Royal BC Museum and UBC Press, 1997–2001), and an earlier account of the region's birds that he co-authored, the *Birds of Pacific Rim National Park* (BC Provincial Museum, 1978). The acknowledgments run to three and a half pages! Black-and-white photographs are scattered through the book—Adrian Dorst is well-known as a photographer, so these illustrations are all high-quality.

Following a brief but informative introduction dealing with the climate, topography, and ecology of the west coast, the story of each species is told in individual accounts of up to four pages. Each species account begins with a short, one- or two-paragraph introduction describing the bird and its global and provincial range, and then proceeds to detail regional habitat use, migration timing and other changes through the year, and trends over the decades.

The accounts are clearly and cleanly written in narrative form and although the subject is scientific, the prose is not technical. This is a book that one can pick up and pick a page at random and enjoy learning about a particular bird during a brief read. A flavour of the style can be seen in sentences like the one describing a recent increase in Hairy Woodpecker records, particularly those by a certain young birder—"Keep in mind that most of us do not have the benefit of Ian's acute hearing" (p. 339). (I have also gone birding with the young man in question and can attest to the acuity of his hearing and accuracy of his identifications!)

Although this is a style that I enjoy, another aspect of the accounts can make the biological story a little harder to follow than it needs to be. What is absent are graphs that could summarize changes through the year, or changes over the decades (for example, a graph of records through the year could quickly show a migration pattern). This may be simply a personal preference but, for readers like me, it would be easier to see those stories visually, rather than read detailed sentences about numbers.

Although the book is focussed on the west coast of Vancouver Island, the author makes sure that the reader knows the big picture story of the region's birds. For

example, he tells the story of the Short-tailed Albatross's near-extinction on its Japanese nesting islands, and mentions threats facing shearwaters on their distant breeding grounds. We learn that the Japanese tsunami of 2011 killed an astonishing 110 000 Laysan Albatross chicks and 2000 adults on Midway Atoll. A detailed account of Canada Goose numbers over time includes a discussion of the effect of the 1964 Alaska earthquake on the breeding geese that migrate through Tofino.

"Nature nuggets" are similarly sprinkled through the text. For example, we learn that Pacific and Winter Wrens diverged as long ago as 4.3 million years and, because Golden-crowned Sparrows love to nip off the tender leaves of garden vegetables, "[l]ong-time gardeners may therefore be more knowledgeable than field ornithologists as to just when the migration period begins and ends" (p. 454). I was surprised to read that Steller's Jays are absent year-round from the Broken Group in Barkley Sound, presumably because they are reluctant to cross an expanse of open water. Another surprise was an account of a small wintering population of Myrtle (Yellow-rumped) Warblers on Stubbs Island near Tofino, where they feed on the berries of "a profusion of wax-myrtle [Pacific bayberry] bushes" (p. 440).

Keen birders know that the west coast of Vancouver Island is a magnet for wandering birds that have gone astray. The book concludes with detailed accounts of the 50 accidental species recorded for the region, from Solander's Petrel (the first well-documented record for North America) and Falcated Duck (I remember the spur-of-the-moment drive from Victoria to 'tick' that one!) to an astonishing Prothonotary Warbler. A further 26 species are listed as "Hypothetical", because they lack photographic or other evidence.

For any naturalist visiting the west coast of British Columbia, this is a valuable reference and an enjoyable book to read. Happy birding!

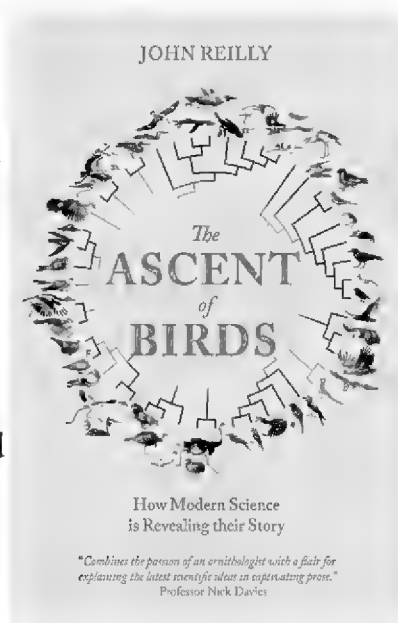
SYD CANNINGS

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The Ascent of Birds: How Modern Science is Revealing Their Story

By John Reilly. 2018. Pelagic Publishing. 340 pages, 31.99 CAD, Cloth.

This book tells the fascinating story of the evolution of birds from their origins in Mesozoan Gondwanaland, which broke up between 130 and 50 million years ago, to their current worldwide distribution. I admit that when I first read the title, I thought this book would be about the dinosaur–bird transition and, while that is covered, it is a relatively minor story in



the book. Reilly starts at the base of the avian phylogenetic tree, with the ratites, a diverse group of flightless birds that include ostriches and rheas, and proceeds chronologically towards the offshoots that gave rise to the finches and tanagers. Dr. Reilly is not a specialist in avian evolution (he had an illustrious career as a haematologist and blood cancer specialist) but combines his scientific training with a life-long interest in birds to present complex concepts and rapidly evolving research in a lively and accessible style.

The book is divided into two almost equal parts: non-passerines (13 chapters) and passerines (14 chapters). Each chapter is spearheaded by a named bird, from tinamous to tanagers, and begins with a look at the evolutionary history of the family or species of the

chapter title, followed by discussion of some of the specialized anatomical, physiological, and behavioural adaptations for those species. An example would be Chapter 5, “The Penguin’s Story: Phenotype and Environment”. While Reilly’s basic question is “how did penguins evolve to survive the extreme polar environment?”, he begins the story some 70 million years ago, in the Upper Cretaceous, when penguins split from other seabirds and then dispersed throughout the Southern Hemisphere. He then discusses their adaptations: changes in feather density and structure that aid in insulation in extreme temperatures; heat “exchangers” in feet and flippers; operation of their flippers by muscles located deep within their warm body and manipulated by long tendons; solid rather than air-filled bones that help deal with dive pressures; haemoglobin modifications to carry more oxygen; and social adaptations such as taking turns shuffling to the outside of the circle when incubating eggs.

Some of Reilly’s “disarmingly simple” questions, such as why are there so many (well over a thousand) South American sub-oscines (the supposedly more primitive members of the passerines that have less well-developed vocal organs than the oscines), turn out to be unexpectedly complex, combining the effects of geographical isolation, geological upheavals, climate change, vicariance, and many unusual ecological niches. Many chapters include phylograms (family trees drawn by comparing gene sequences from different species) to show evolutionary relationships of bird families, which is the basis for most of the author’s stories. Phylograms are really just scientific hypotheses waiting for more data to confirm or refute them, or for new analytical techniques to be developed. Because Reilly’s

career is not invested in the research, he even-handedly discusses conflicting hypotheses and interpretation of data in a number of instances. The advent of molecular genetics has enabled taxonomic relationships to be revealed, resulting in many recent changes among taxa. For example, Hepatic (*Piranga hepatica*) and Scarlet (*P. olivacea*) tanagers have traditionally been classified within the Thraupidae (Tanagers), but they are now known to be cardinals, while honeycreepers, seedeaters, conebills, saltators, Darwin’s finches, and flowerpiercers are really tanagers ... a good excuse to get a new field guide every year!

The occasional simple map shows the movement of continents or the dispersal routes of species. The 37 colour plates in the middle of the book, comprised of 51 images, complement the text. There is a tremendous volume of supplementary material, including a timeline, a chart of geological ages, a comprehensive glossary, 32 pages of chapter notes and citations (in reduced type), bibliography, list of species (376) mentioned in the text (in a nice touch that section is titled “Dramatis Personae”), and an index. The bibliography is rather short (three pages) because most of Reilly’s sources are primary papers, of which there are no end of interesting ones to follow up on in the notes section.

While this book is a little daunting at first, covering as it does the entire evolutionary history of birds, the author does an excellent job of breaking the latest science down into understandable chunks, and I highly recommend it as an excellent synthesis of this amazing field of research. You won’t look at birds the same again.

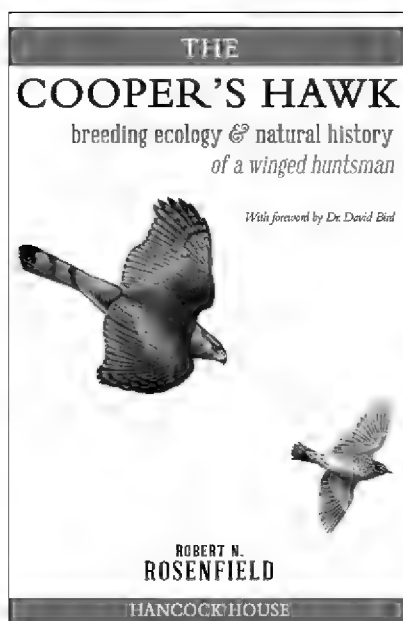
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The Cooper’s Hawk: Breeding Ecology & Natural History of a Winged Huntsman

By Robert N. Rosenfield. 2018. Hancock House. 164 pages, 49.95 CAD, Cloth, 34.95 CAD, Paper.

One could think of Cooper’s Hawk (*Accipiter cooperii*) as a “feeder bird”, because it frequently hunts mid-sized birds attracted to feeders, such as sparrows, starlings, and doves, and chipmunks that are attracted to spilled seed. They hunt mostly ground- and shrub-foraging birds and small mammals from a perch, scanning for movement, followed by a sudden burst of flight. They will even run after prey on the ground or dive into thick cover in pursuit. Having evolved as a forest raptor, with adaptations for



swift flight through tight spaces, the species has adapted well to fragmented urban environments with abundant prey as long as there is nesting habitat.

In his Preface, Rosenfield sets out three goals for the book: 1) to aid the curious public in interpreting the behaviour of Cooper’s Hawks and to recognize their ecological contexts, 2) to serve agency and academic biologists charged with management of raptors, and 3) to prompt new questions for study. The author tackles these goals in six chapters, broadly titled as: “You are What You Eat”, “Courtship and Nesting Biology”, “The Breeding Population and Habitat Suitability”, “Individual Traits (the Descriptive Currencies of Natural History Dynamics)”, and “The Meaning and Implication of Natural History Variation”.

I think the author achieves these goals admirably. This book is a well-written account of the natural history of Cooper’s Hawk, based on the author’s own 38 years of research in Wisconsin and other studies in

British Columbia, North Dakota, Arizona, and Florida. It is a good example of how a long-term study of a single species (six generations) enables a researcher to explore questions they didn't even know to ask in the beginning. Rosenfield is an author on approximately one-quarter of the papers in the lengthy reference section, but he enlivens his research results with incidental observations to weave a compelling story. The text is supplemented with numerous photographs with extensive descriptive captions that are a significant addition to the information presented. There are a few maps and sketches.

The problem I have with the book is the layout. The 15 cm × 23 cm size is very nice, but to achieve that the publishers used very narrow margins, such that to read the text near the spine you must force the book flatter. Most photos 'bleed' right to the edge of the page, including the bound edge such that part of the photo is effectively hidden. Multiple photos are laid out side-

by-side with no border or white space to separate them or give eye relief. Many photos appeared to be very grainy, perhaps the result of scanning original slides at insufficient resolution or cropping distant photos to emphasize the bird in the picture. And captions run very tightly to the edge of the photos. These layout choices were undoubtedly influenced by trying to keep the number of pages to 164—most book printing relies on 'signatures' in multiples of four for more economical printing. I doubt if any of these decisions were Rosenfield's.

While I found these layout issues distracting, I do recommend this book to anyone interested in Cooper's Hawks. As Rosenfield says in the final chapter, "... without comprehensive natural history accounts of where a species lives, how it behaves, and what it eats, a species is simply a dot on a graph" (p. 133).

CYNDI M. SMITH

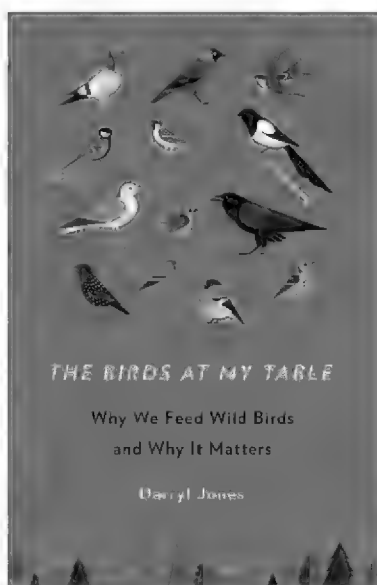
Canmore, AB, Canada

The Birds at My Table: Why We Feed Wild Birds and Why It Matters

By Darryl Jones. 2018. Cornwell University Press, Comstock Publishing Associates. 352 pages, 19.95 USD, Paper.

The central purpose of *The Birds at My Table* is aptly explained by the subtitle *Why We Feed Wild Birds and Why It Matters*.

While it may at first seem unlikely that Canadian naturalists would be interested in a book on bird feeding written by a behavioural ecologist from Australia, the author delivers an exceptional overview of both the science and art of



intentional bird feeding throughout the world. It is not at all a how-to book on feeding birds, but rather an exploration of the human, avian, and economic dimensions of what was once a simple backyard process engaged in by people around the world but is now a global industry. The author takes a common, almost universal human-wildlife interaction that many may never have thought about deeply, and highlights its major implications, both positive and negative, for wildlife ecology. The book explores many aspects of bird feeding that I never really contemplated, despite having fed birds for almost my entire lifetime. Many dimensions of bird feeding are delved into, from the early history of bird feeding and the huge growth in the bird feeding industry, the debate over whether to feed just in the winter or year-round, the effects of supplementary feeding on bird populations, human perspectives on and reasons for bird feeding, the role of bird feeding in disease transmission,

the valuable role of citizen science in monitoring bird populations, and supplementary feeding as a species recovery and conservation measure.

The author makes it clear that he was not an expert on the science of feeding birds when he first initiated his research. He is refreshingly candid and open about what his expectations were and what findings surprised him, and engagingly and understandably conveys those lessons to the reader. The informative and eloquent style kept even the Acknowledgement section interesting and engrossing.

The history and diverse facets of bird feeding around the globe are informatively presented. To many, bird feeding is a common phenomenon of little ecological or social importance. But it is now virtually a global phenomenon, and it is easy to forget that the first mass marketing of wild bird seed and feeders only began in the 1960s. The scale of bird feeding is astonishing, and the author presents interesting and sometimes staggering statistics without resorting to dry facts. For example, in the United States alone 20 000 railway cars-full of black sunflower seed are sold annually, globally over one million tons of seed are sold annually worth \$5–6 billion, in New Zealand over 5 million loaves of bread are fed to birds annually, fully one-half of the population in many countries feeds birds, and in the United Kingdom enough bird seed is sold annually to support many times the populations of birds being fed.

The book provides an interesting summary of the history and evolution of bird feeding, from the casual sharing of available food scraps with neighbourhood birds to the deliberate, year-round feeding of birds using manufactured feeding devices and food grown spe-

cifically for the bird feeding market. The metamorphosis of black sunflower seed in just a few decades from a native plant cultivated by indigenous peoples of North America and consumed naturally by relatively few bird species to the primary seed fed to and consumed by birds globally was a fascinating story. Interesting parallels are drawn between the growing environmental consciousness in the early 1900s, the conservation movement and the establishment of the first USA national parks, and a growing public interest in bird feeding that led to a rapidly expanding demand for wild bird feeding and feeding products.

A truly international picture of bird feeding today is presented. The anecdotes and references are taken from many countries, and the author interviewed experts from many countries in the course of his research. There are many Australian, New Zealand, and European references, and from a North American perspective it is interesting to learn about the similarities and differences of bird feeding habits and perspectives elsewhere in the world. It was enlightening to learn that bird conservation agencies around the world hold very different and sometimes completely contradictory perspectives on major questions, such as whether to feed birds only in winter, year-round, or not at all.

The book is thoroughly researched and solidly referenced, although there has been surprisingly little research until recent decades. While noting the limited availability of scientific information, he has compiled a diverse array of both current and historical resource materials from the scientific literature, bird food supply companies, bird conservation agencies, and others. The available scientific literature has been thoroughly gleaned and summarized. Without compromising the integrity of individual studies, Jones presents complex and complicated results in a way that the lay audience can understand. This is not easy, as many studies come to different or even contradictory conclusions. Without sparing readers from the challenges of inadequate research, differing techniques, differing species ecology, and inconsistent results, he familiarizes them with the challenges of scientific investigation and interpretation of results. He succinctly provides general conclusions and observations on bird feeding, while still recognizing the complexity and diversity of results, and notes when his conclusions or suppositions are hypothetical or based upon subjective evaluation. References are presented by both chronological footnotes by chapter as well as an alphabetical listing by author. Unfortunately, this method is clear but cumbersome and somewhat inefficient, requiring double the effort to find a reference; sometimes the same reference is cited several consecutive times, but there is no way to know this until the chapter summary is consulted.

Areas where scientific research and documentation are limited are clearly identified. The author saves his greatest incredulity for the lack of research, and his most overt indication of humour for the “virtually uni-

versal pastime of ‘feeding the ducks down at the lake,’ a practice that leads to untold tons of bread being tossed to waterfowl the world over” (p. xiii). But the humour is ironic, however, for Jones goes on to note the dual result: “bringing joy to millions and often resulting in the eutrophication of urban lakes and a host of attendant ecological problems” (p. xiii). He returns to this topic later in the book, so clearly he is very interested in, and perturbed by, the amount of bread fed to waterfowl and frustrated over the lack of research on the implications of this practice.

The book is well written and edited. It was a bit surprising that there was only one passing reference to the potential implications of extensive supplemental feeding for natural selection, given the dramatic effects on bird survival and populations; I assumed that this topic would have featured much more prominently. It was also surprising that, although there were references to many types of food and birds around the world, the supplementary feeding of nectar-feeding birds such as hummingbirds was not mentioned. There was one minor misrepresentation of biological fact that can be forgiven in a Southern Hemisphere author: Black-capped Chickadees are referenced as being at the northern limit of their range in Wisconsin, when in reality they occur almost as far north as the treeline.

Many unique and interesting aspects of avian ecology and conservation are mentioned throughout the text. This includes information on species such as the Monk Parakeet, an aggressive invasive in the eastern USA that is sustained in winter only through the use of feeders, Noisy Mynas in Australia that are attracted by the planting of native nectar-bearing shrubs and then exclude most other species through their aggressive territorial behaviour, and the role of supplementary feeding in the recovery of species at risk such as Red Kite (United Kingdom) and Takahe (New Zealand).

The chapter on disease transmission was a fascinating and sobering summary of the known and potential role of feeders in the dissemination of avian diseases, through both viral transmission where birds congregate and tainted foods such as peanuts with aflatoxins.

This book will be of interest to both naturalist and scientific audiences interested in the art and science of feeding birds. North American readers will get a refreshing and interesting global perspective on bird feeding. Readers will find that the answers to the basic question, *Why We Feed Wild Birds and Why It Matters*, are both simple and complex, and they will find much to ponder in this book. Those who feed birds will come away with a renewed understanding and awareness of the role of supplementary feeding in the ecology of birds, and will look at feeding birds in a new and broader way.

TED ARMSTRONG

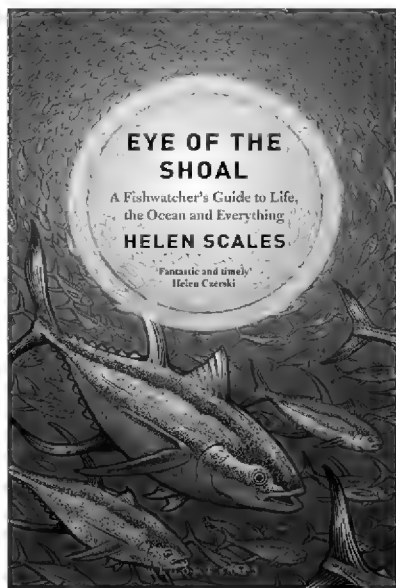
Thunder Bay, ON, Canada

ZOOLOGY

Eye of the Shoal

By Helen Scales. 2018. Bloomsbury Sigma. 320 pages, 36.00 CAD, Cloth.

This book is an excellent example of a highly qualified professional researcher distilling the most interesting parts of her subject to create a coherent, enthralling work. Like her previous book, *Spirals in Time: The Secret Life and Curious Afterlife of Seashells* (Scales 2015), *Eye of the Shoal* is a 'deep dive' into the history, ecology, and complexity of life in the watery realm. Of the two, *Eye of the Shoal* is by far my favourite.



The 10 chapters cover the past and present representatives and ecologies of "fish", that nebulous group of (usually) water dwellers who (often) have scales and display an impressive diversity of colour, behaviours, diet, habitat, and talents. Although at least a passing interest in fish or aquatic ecosystems will probably help, this book is written for a broad audience and requires no specialized knowledge to enjoy. Latin names are only given if their translations are relevant or interesting, and the history of fish research is treated with humour and based in the quirky personalities of those who were involved in it.

The author is trained as a marine biologist and her field experience in marine ecosystems combines with a presenter's sense of organization to create an eminently readable book. Unlike some works in the genre, Scales lets the subject speak for itself. Yes, you may come away caring more about the health and preservation of earth's fishy residents, but it will be because the author showed you the wonders of that world, not simply because she told you to care.

The text is organized in sections, many one or two pages long, covering a specific topic. This structure makes for an excellent sporadic read (short reading over a cup of hot caffeinated liquid of your choice, or before bed), but there is a well-crafted, logical flow to each section and the text does not feel fragmented, disorganized, or repetitive.

Helen Scales writes with many excellent habits that are the hallmark of great general science writing, including humanizing science. Where appropriate and without the impression of haphazard name dropping, discoveries and studies are contextualized with the location and name of the researchers leading them. This allows interested readers to look up these projects and adds a face and context to facts and discoveries.

This book feels like a passion project in the best possible way and includes several delightful touches that put it a step above other entries in the genre. Each chapter begins with a full-page drawing by scientific illustrator Aaron John Gregory capturing the themes and main species of the chapter, each of which is annotated in the back material with a species list. Continuing the attention to detail, sections within a chapter are separated by a small fish, with each chapter having its own dedicated icon. A final touch: each chapter ends with a short traditional fish myth, its origin, and its own thematic illustration.

The author's easy to follow, narrative prose combined with her contagious enthusiasm make *Eye of the Shoal* one of the most enjoyable popular science books that I have read.

Literature Cited

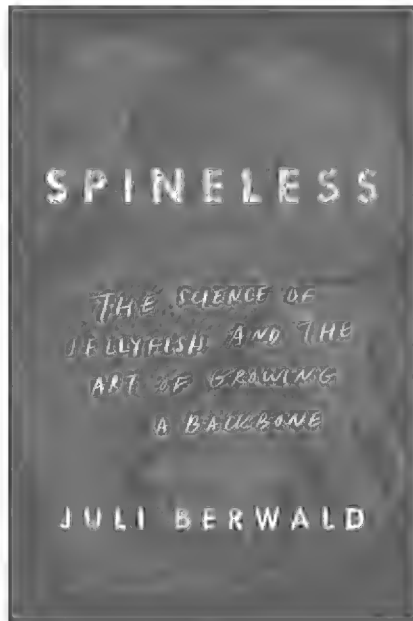
Scales, H. 2015. *Spirals in Time: The Secret Life and Curious Afterlife of Seashells*. Bloomsbury Sigma, New York, New York, USA.

HEATHER A. CRAY
Waterloo, ON, Canada

Spineless: The Science of Jellyfish and the Art of Growing a Backbone

By Juli Berwald. 2018. Riverhead Books. 352 pages, 16.00 USD, Paper.

Spineless is primarily a popular science book, with a dash of memoir thrown in for good measure. The two-part subtitle—*The Science of Jellyfish and the Art of Growing a Backbone*—reflects both elements of the writing. *The Science of Jellyfish* accounts for most of the book, and what you would expect from a well-written, well-researched non-fiction



science book. The second part, *the Art of Growing a Backbone*, unfolds haltingly throughout the book, culminating in the final page of the last chapter. The memoir component is the personal story and thesis of the author, her journey to jellyfish science and speaking up for ocean health.

The author holds a Ph.D. in ocean sciences, and her interest in jellyfish stems from formative experiences during her undergraduate and graduate programs. Not a jellyfish researcher herself, the somewhat winding narrative element describes an intellectually bored writer, editor, scientist, and mother developing a burning interest in jellyfish at an age when her family vacation time could be planned to coincide with researcher interviews and fieldwork adventures. Although it can be a bit disjointed at times, the personal story of the author and the process of her enmeshment in the world of jellyfish science come together well in the last third of the book. This mix, science fact punctuated by personal moments of the author's life and experience, sets this book apart from many popular science works. Whether or not you enjoy the threads of personal narrative will likely depend on your own experiences and perspec-

tives, but they are by no means the dominant element of the work.

Spineless is a book to suit a broad audience. It certainly has enough fascinating information, new research, and unanswered questions to satisfy interested readers. The book probes and highlights the many unknowns of jellyfish: where they grow, what they eat, and what eats them. Topics explored include jellyfish biology, ocean acidification, commercial fishing, and invasive species. Compared with other popular science works, this is a longer book, not the average short romp through a subject, and the print is small, making it longer than it looks. This allows space for interviews and research conducted over many years, all of which is meticulously cited in the "Notes" section at the end of the book.

Ostensibly organized into parts of the jellyfish life cycle—Planula, Polyp, Strobila, Ephyra, and Medusa—the writing doesn't seem to closely follow this logic, except for the last section which links to the previous pages in the author's jellyfish journey. Although a few gorgeous drawings of jellyfish life stages are included, the book would have benefitted from some additional illustration, particularly depicting the main species discussed. As it is, image-oriented readers may find themselves switching intermittently to a web browser or making notes for later. The writing quality is very good throughout. Although the feel of the writing changes in the last third or so of the book where the author includes her own and her family's personal experiences with jellyfish science and expeditions, the author's prose is easy to follow and usually descriptive enough to make up for the lack of images.

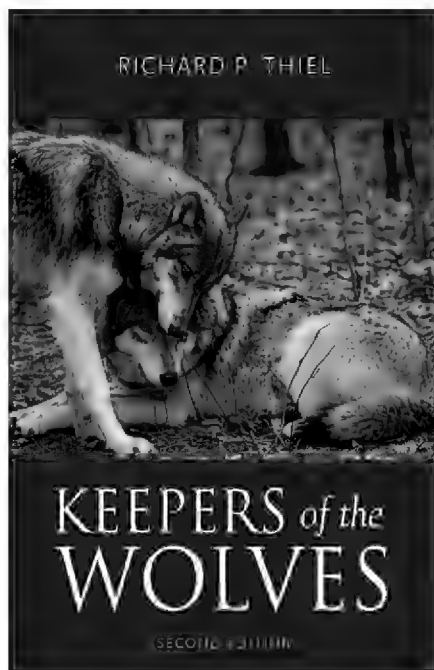
Exploring jellyfish research through the lens of a devoted hobbyist and interviewer turned collaborator, this book reveals the remarkable knowns and surprising unknowns of jellyfish and their role in the future of our oceans. It is well worth a look.

HEATHER A. CRAY
Waterloo, ON, Canada

Keepers of the Wolves. Second Edition

By Richard P. Thiel. 2018. University of Wisconsin Press. 264 pages, 22.95 USD, Cloth.

Keepers of the Wolves by Dick Thiel is a very enjoyable read tracing the extirpation of Gray Wolves (*Canis lupus*) in Wisconsin, the early stages of recovery in the late 1970s–1980s, to the current recovered population of over 900 wolves inhabiting the state. This book was written by a wolf biologist, so there are great descriptions of his experiences studying wolves with



numerous anecdotes of his encounters with individual wolves, especially early in the recovery process. While I may be biased because I have written a similar book of my experiences as a wildlife biologist studying Eastern Coyote/Coywolf (*Canis latrans* × *lycaon*) in Massachusetts (Way 2014), I absolutely love these kinds of books because you get to read about an animal from the person who experienced it first-hand. In this case we go back to 1978, when there had been no resident Timber Wolves (as they are called in the book) in Wisconsin for about 20 years. While packs were living nearby in bordering Minnesota, there was only the occasional sighting in Wisconsin which were surely dispersers from Minnesota. Thiel became interested in wolves when he was in high school and was determined to discover if wolves had indeed returned. In his college years, he conducted wolf track surveys in the winter-time and howling surveys over the summer to document their presence.

Thiel worked as a temporary (with no seniority accrued) biologist for the state of Wisconsin for about a decade as he led the wolf recovery team up until 1989. The book details the experiences, awe, aggravation, absurdity, and hardships (such as frigidly low temperatures) encountered as a field biologist and, unfortunately, the politics and associated public relations nightmares that go along with studying a controversial animal. We learn of individual wolves such as Big Al, Deborah, Gimpy, and Mailrunner, which he decided early in the study to name for ease of describing and remembering (pp. 95–98). I really appreciated that section given that he was a state employee at the time and naming animals is often a taboo for biologists, especially those affiliated with wildlife agencies as most would view naming as being biased in their attachment to the animals. As I discuss in Way (2014), however, I do not know how it is possible to be non-biased when you do anything that involves pouring your heart and soul into an endeavour,

and recent research supports that (see Johns and Del-lasalla 2017). Thiel gave great descriptions of the human-populated Wisconsin landscape when he digressed and added anecdotes on his research subjects such as when he foot-hold trapped, drugged, and then followed via radio-telemetry his study subjects by vehicle and small aircraft, cruising the many fire roads in northern, and eventually central, Wisconsin.

We also learn of humorous events which occurred during his research which is typical of any biologist's experience. While detailed throughout the book, the chapter "Murphy's Law"—which states that anything that can go wrong will go wrong—brings many of these situations to life, such as when his car key fell into a snow-bank (on a Friday afternoon no less). Or when he almost got into a plane crash on a frigid day when the plane went from barely starting to taking off with only the biologist in the plane as the pilot was outside trying to get it moving. Or when he was tracking a wolf and had to floor his vehicle through a flooded stretch of a dirt fire road. But the fun didn't end after he crossed the water, as he soon locked himself out of the car when he stopped to pick up a wolf scat he found. He ended up having to pick the lock to open the door. While these stories are certainly laugh-out-loud-while-reading-moments, they surely were quite aggravating when they were happening.

The chapter "Boy, Would I Love Your Job!" is also a bit comical. Thiel started with the pretense that being a wolf biologist would be an amazing living, but then went on to describe several uncomfortable positions that he found himself in, including more than one experience talking to wolf-hating hunters at local bars. Many times, he pretended to be someone else and never revealed to his counterparts that he was the actual biologist they were complaining about. I chuckled while reading these passages. In addition to the human perspective and many cold days in the field (similar to the "Murphy's Law" chapter), the other take-home from this chapter is the fact that the bureaucracy associated with the job can make one go mad, especially when people are in a political appointment with minimal science background—aka the natural resource old boys (p. 164). I feel for Thiel, as I was not only naïve about departmental politics but also loathed its influence on decision making (p. 165), and so it is perhaps not surprising that both of us lost our research careers over it (see "They Shoot the Messenger, Don't They?" and Way 2016). Thiel's descriptions of his emotions alternating between separation anxiety and intense anger are spot on (pp. 18, 184).

I read the original version of *Keepers* back in 2001 and shared in the excitement as Thiel and his colleagues found wolf tracks in the snow, howled in the forest night and were answered back, learned to safely trap wolves

to attach radio collars, and tracked the packs' ranges by air from a cramped Piper Cub. Following the stories of individual wolves and their packs as pups were born and died, when wolves were shot by accident and by intent, and ravaged by canine parvovirus and hard winters was why I loved the read. So it was with excitement that I had the opportunity to review this second edition which kept the original first 11 chapters and replaced the last three with updated information and a concluding Epilogue. This new version brings Thiel's story into the 21st century, recounting his work monitoring wolves as they spread to central Wisconsin, dealing with conflicts between wolves and landowners and recreationalists, following changes in state and federal policies, the establishment of a state wolf-hunting season in 2012, and Thiel's forecast for the future of wolves in Wisconsin. We learn that Thiel takes his first truly full-time job as an environmental educator in central Wisconsin, near his home, where wolves soon follow by returning to the Central Forest region.

By 1999 (when the first edition went to press), there were an estimated 200 Timber Wolves in 54 packs in Wisconsin. In 2017, there were an incredible 925 wolves living in 232 packs (pp. 221–222), an amazing recovery to the point where various stakeholders are polarizing wolf management. On one side are environmental groups and animal lovers suing to prevent any hunting and on the other a hyper-conservative government that took over in 2010 (pp. 206–207) and removed any semblance of science from a once prestigious wild-

life department and is now closing the door to future opportunities by catering to extreme anti-environmental populism (p. 221). Perhaps Thiel's closing quote correctly summarizes the current situation of wolves in Wisconsin, "Wolves will persevere despite society's ineptitude as custodians of wildlife" (p. 228).

This book is right in my wheelhouse and I highly recommend it. If you ever want to learn about something go straight to the source. In the case of wolf recovery in Wisconsin, there could be no better person than Thiel, because he was there when wolves returned and is still around as wolves have recovered to the point of being the most abundant that they have been on Wisconsin's landscape in well over a century.

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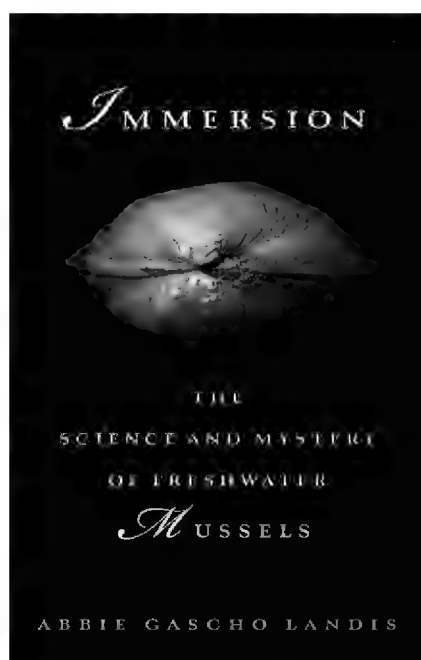
JONATHAN (JON) WAY

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Immersion: The Science and Mystery of Freshwater Mussels

By Abbie Gascho Landis. 2017. Island Press. 256 pages, 34.50 CAD, Cloth or E-book.

Immersion is a book about freshwater mussels: what they are, how they live, why they matter, why so many of them are imperilled, and how we can change that. Best described as a popular science book, this is no sterile examination of freshwater bivalves. The writing is funny and charming, equal parts accurate, informative description, and



transportive narration. In addition to presenting a compelling argument for why freshwater mussels are fascinating creatures, *Immersion* explores tensions between water for crop irrigation and water to keep the river flowing, the *Endangered Species Act* versus corporate

interests, and mussel researchers versus the onslaught of pollution, habitat loss, and fragmented landscapes.

A self-professed freshwater mussel groupie, the author is a writer, veterinarian, and naturalist. She is also the wife of a freshwater mussel biologist and the mother of two creek-loving toddlers. Sourced from field and laboratory visits with experts as well as her own museling experiences, the ten chapters are well organized and coherent, covering mussel reproduction, research, and restoration in engrossing detail. The selected bibliography provides further reading for the dedicated enthusiast, including peer-reviewed journal articles from the scientists whose work is featured in the text as well as news pieces and reference texts. Individual chapter sections vary in length but none are overlong or feel bloated. As each section is a logical and relatively self-contained parcel nested within the chapter's thematic whole, the structure of the book lends itself both to casual and to binge reading styles. The line drawings peppered throughout the book are few but effective, illustrating key details in harmony with the text. The author's prose is appropriately descriptive and I was

certainly not left wanting for illustrations to visualize the subject matter.

This book ignites a sudden and urgent impulse to grab a snorkel and run to the nearest riffle. If you live in northern latitudes, I recommend reading *Immersion* in the early warm weather months, so that you can satisfy that urge when mussels are active (and without the need for a polar bear dip). It is the quality of writing and depth of enthusiasm for the topic that sets this book apart from other similar popular science books. Instead of passively informing the reader about an interesting topic, the author and the researchers within the pages

carry you with them into their streams and laboratories. Like them, you may catch yourself proselytizing about mussel biology to friends and strangers alike.

This is not a book you will want to part with, instead revisiting it from time to time to refresh and revisit. If you are new to the world of freshwater mussels, this book is guaranteed to change the way you look at your local creeks, rivers, and streams. I can (and do) enthusiastically recommend this book to anyone with so much as a glimmer of interest in the natural world.

HEATHER A. CRAY

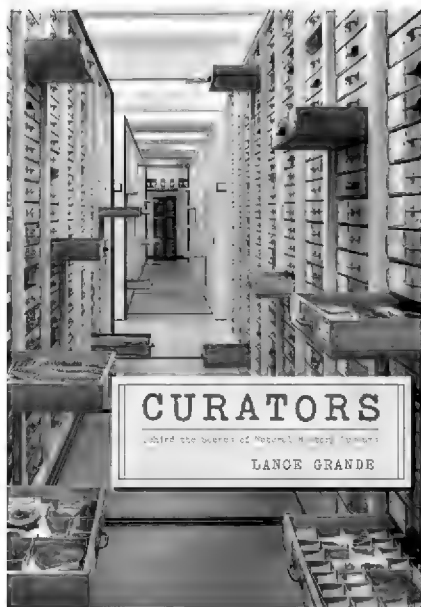
Waterloo, ON, Canada

OTHER

Curators: Behind the Scenes of Natural History Museums

By Lance Grande. 2017. University of Chicago Press. 432 pages, 35.00 USD, Cloth, 21.50 USD, E-book.

Museums are, perhaps, best known for exhibitions. When visitors walk into any major museum, galleries and exhibits are the first things they see so it's easy to assume that these are the museums' main function. True, museums are about exhibitions, but they are also about so much more. Museums collect, conserve, communicate, and research, in



addition to developing displays. In fact, most large museums have only a fraction of their collections on display. Much of a museum's activity goes on behind the scenes, in the research and collecting by curators. Their projects often provide content for exhibitions, in the form of spectacular specimens and their associated stories. However, curators' work remains essentially unknown by museum visitors. Lance Grande explores this unknown realm in *Curators*, his behind the scenes examination of curatorship.

So what, exactly, does a curator do? "I came to realize that few people understood what a natural history museum curator does", writes Grande in his Preface (p. ix). I smiled wryly as I read his lament because I too have received blank looks when I have told people I am a museum curator. It's not a career that's well known, though it is one that can be filled with interest, variety, and opportunities, as Grande's life story well shows. According to his succinct definition, a natural history curator is a "research scientist whose job is to bring authority and originality to their museum's scientific mes-

sage" (pp. ix–x). Curators accomplish this through "original research" and the dissemination of "knowledge of scientific discoveries to students, other scientists, and the general public" (p. x). Interestingly, Grande's definition does not include developing natural history collections, though those collections derive in part from research activities, in particular fieldwork. Building and caring for collections are usually significant components of the job description and occupy much of a curator's time. Nevertheless, much of Grande's narrative does in fact focus on collections, how they are acquired, used, displayed, and maintained for the future. For anyone who has donated natural history specimens to a museum, this book provides insights about what happens to them and how they may be used.

Working for one of North America's major museums, Grande has had many opportunities for research, travel, and participation in diverse projects. His account is arranged roughly chronologically, following his career from a student interested in fossils to a senior museum administrator. Grande is primarily a palaeontologist with a focus on the fossil record and the history of life. Thus, much of his narrative, especially in the earlier chapters which deal with his education and early career experience, describes his fieldwork and collecting. His research focus has been fossil fishes, chiefly those from the Green River Formation in Wyoming. He proudly records that he has worked in his field area for 41 field seasons, as of 2015 (p. 63). Later in his career, he moved into more administrative roles, which were accompanied by different sets of challenges. His focus increasingly shifted from research to management, including issues management, balancing staffing and programs, and securing funding and outside support for specific projects. This progression gives him the opportunity to talk about many aspects of a curator's

life, including dealing with some of the ethical and practical issues around collecting and collections.

For many readers, the Field Museum in Chicago will perhaps be best known as the home of SUE the T-rex, who features prominently in the museum's promotional imagery and who even has a snark-rich Twitter account. The story behind the Field Museum's acquisition of SUE is lengthy, complicated, and fascinating, highlighting the difficult issues that arise when specimens of high scientific value also have high commercial value. As the most complete *Tyrannosaurus rex* found to that time (1990), SUE's ownership was contested from the beginning, an acrid controversy only resolved in court. Thereafter, the fossil's sale generated global interest, tension, and media hype. On 4 October 1997, Sotheby's sold the specimen to the Field Museum in a nail-biting auction. Securing SUE cost the museum more than eight million dollars (p. 133).

Although this specimen was secured for a major museum that recognized its tremendous display potential, scientific significance, and educational value, the story does raise questions about the commercialization of fossils. Grande argues that commercial fossil quarries are important to museums and points out that his own work on fossil fishes, in Wyoming and Mexico, was facilitated by cooperation with commercial fossil extraction. He reasons that some localities "could not possibly be adequately sampled for scientific study without the help of amateur and responsible commercial interests" (p. 43). On the other hand, many fossils are found purely opportunistically through industrial, mining, and development activities. Specimens may be revealed when large-scale disturbances expose fossil-bearing bedrock or sediments. A recent exhibition, "Grounds for Discovery", at the Royal Tyrrell Museum in Alberta highlighted exactly these kinds of chance finds. Good collaborative relationships can result in serendipitous specimens becoming part of museum collections.

Collaborative work also happens across disciplines. Grande describes one such long-term fruitful collaboration in his career, with an ichthyologist, Wally Bemis from the University of Massachusetts, who studies modern rayfin fishes. Their fields of expertise are complementary: Grande on skeletal anatomy, and Bemis on soft tissue anatomy. Studying modern fish specimens helped Grande to understand the structures he was seeing in the fossil record. Bemis obtained many specimens through donation at an annual marine fishing tournament off the coast of Alabama, which Grande describes as "a boon to fish research" (p. 96). Bemis ran a contest for "Most Unusual Fish" and through this and a filleting service was able to secure many large, rare, or unusual fish specimens. Besides enhancing the Field Museum's collection, specimens also went to other museums, universities, and institutions. Collections come from many sources, some not so obvious!

Notwithstanding his focus on palaeontology, Grande introduces the other curatorial programs at the Field

Museum. On the natural history side, the museum supports curators in botany, lichenology, ornithology, geology, meteoritics, marine invertebrate zoology, and entomology. The museum also supports several human history curators, including those focussed on cultural anthropology, archaeology, ethnology, and physical anthropology. This reflects the traditional subdivision of most large museums into natural history and human history sections. Field Museum curators travel to all parts of the globe. Grande mentions research projects that have taken place in Israel, Russia, Mexico, and many other countries in Europe and Asia. Grande emphasizes that interdisciplinary work at the museum is facilitated by the relatively small number of curators, 21 in 2014 (p. 158), and that the closeness of the group often leads to fruitful collaborations. This echoes my own experience as a curator. Many Field curators also mentor and supervise graduate students and thereby train the next generation of researchers and curators. Being a natural history curator is indeed a multifaceted job!

Museum collections aren't "owned" by curators; they are preserved and handed down from curator to curator. This means that specimens are available for re-investigation when new analytical techniques become available. Grande provides a particularly noteworthy example of this in the story of the "Man-eaters of Tsavo". These lions terrorized rail constructions crews in Kenya in 1898 until they were shot and killed by John H. Patterson, who later sold the skins and skulls to the Field Museum, where the taxidermied specimens went on display in 1926. In the early 2000s, the Mammals curator, Bruce Patterson (no relation to the hunter) re-examined the skulls. He found that one of the lions had severe dental problems that undoubtedly caused pain and difficulty catching and killing regular prey. Hence the animal probably turned to the easier caught and killed railway workers as a food source. Grande also points out that the century between collection and re-examination also spans a substantive change in attitude towards wildlife and "Big Game". Nowadays, Field Museum curators are heavily involved in conservation efforts for wildlife and ecosystems in many areas of the world.

Curators may also participate in exhibit development, which can provide a tremendous outlet for creativity and originality. With extensive collections across natural history and great depth of expertise, there is usually no lack of high-quality specimens and story ideas. Natural history lends itself well to display. What is challenging is telling these stories and displaying the specimens in a way that is meaningful and engaging to visitors. This requires attention to the scientific importance of the material together with other qualities such as beauty. Grande emphasizes the aesthetic gaze when describing his contribution to the re-development of a gallery showcasing gemstones and jewelry. Exhibit development requires collaboration between curators and

professionals with different skills, such as designers, educators, and fabricators. When this succeeds, the results can be breathtaking.

For anyone interested in natural history collections, Grande's account is a great read—lucid, entertaining, and informative. The book is beautifully produced with a clear font on high quality paper. With its modest \$35 price, it is exceptional value for a high-end hardback book. Notably, it contains abundant colour images. Each chapter is followed by a half-dozen or more pages of colour images that directly relate to its topic, ending with an image that serves as an introduction to the next chapter. I really enjoyed this interweaving of the narrative and images. It was extremely effective in reinforcing the messages of the text. I especially liked

the images of specimens that Grande has collected and studied and the pictures of his field crews. These show that the collections are a collective effort and the efforts of many people are involved in their curation and long-term preservation. Without field assistants and skilled preparators back in the lab, museum collections would not be accessible for research or display and the research opportunities for curators would be limited. Although Grande's book is focussed on his career as a curator, his ultimate message is that the museum is an institution that benefits from the skill and dedication of many professionals from different fields.

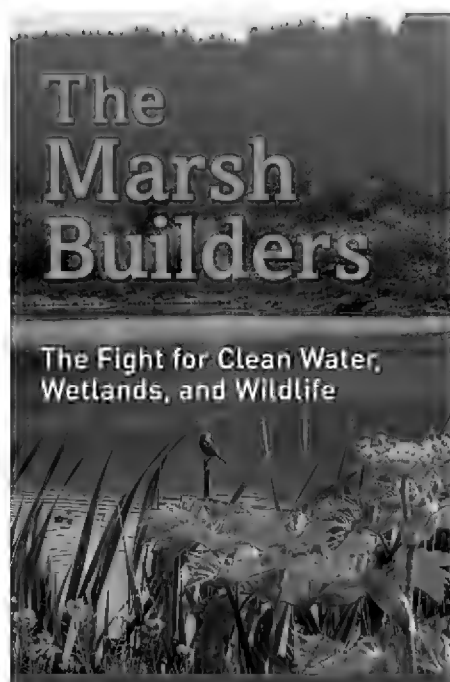
ALWYNNE B. BEAUDOIN

Royal Alberta Museum, Edmonton, AB

The Marsh Builders: The Fight for Clean Water, Wetlands, and Wildlife

By Sharon Levy. 2018. Oxford University Press. 248 pages, 39.95 CAD, Cloth. Also available as an E-book.

The Marsh Builders, a book about constructed wetlands? Well not exactly, but that appears to be what inspired Sharon Levy to embark on this historical account of human waste, wetland destruction, and the United States' *Clean Water Act* (CWA). The actual "marsh building" doesn't start until around halfway through the book!



Humanity's relationship with the environment has changed dramatically over the past 200 years. We all know this, but to write a book that documents our history from the perspective of human waste, wetlands, and water pollution is unique. Levy has obviously done extensive research; in fact, there is an extensive list of numbered references at the end of each chapter. As a result, the book provides an insightful and vivid account of the science and politics of dealing with a very real problem—what to do with human waste as cities like London and Berlin develop with populations of over a million people and growing. Piping waste to the nearest watercourse is fine, until your neighbours downstream become ill. The book draws the reader in with the first chapter, "Cholera's Frontiers", set in London, England, around 1850.

Chapters 2 and 3, "The Tides of Change" and "The Microbe Solution", document our evolving understanding of disease and its link to human waste. Initially dis-

ease was thought to arise from miasma, or the stench of human waste, but new tools, such as the microscope, and scientific approaches to treating human waste, such as the activated sludge process discovered in 1914, began to inform the politics of urban planning. Elected officials, then as now, were responsible for public well-being and, working with limited funds and the best knowledge of the day, approved infrastructure projects to deal with human waste. The CWA created in 1971 transferred authority over sewage and industrial effluent regulation from individual states to the federal Environmental Protection Agency (EPA), mandating "a wildly idealistic goal that all such discharges into US waters should cease by 1985" (p. 75). To this day, individuals living in cities simply flush the toilet and turn on the tap for clean water, with little thought of the long and continuing struggle to make this system work. Herein lies the heart of *The Marsh Builders*, the tension between science, politics, and human waste.

Chapter 6 describes "Fighting the Big Machine"—aka the Humboldt Bay Wastewater Authority (HBWA)—versus the small-town politics, petitions, committees, and legal battles that delayed conventional approaches to wastewater treatment long enough for a treatment alternative to emerge that would be replicated around the world. Levy gives a detailed account of the small, feisty town of Arcata, located on the Pacific coast of northern California, and its fight with the HBWA. It's a classic story of David fighting Goliath: big government with federal funding intended to build a sewage treatment megaproject connecting small towns with a pipe running under Arcata Bay to a regional treatment plant on Humboldt Bay. Each town along the route was expected to join the project, including making enormous, sometimes bankrupting, financial contributions to building and maintaining the infrastructure.

Arcata had a different vision for wastewater treatment: a low cost, low energy, local solution using open surface water wetlands that would meet CWA guidelines, create wildlife habitat, and improve the ecology of Humboldt Bay. However, this had never been done before and few believed it would work. It was a fight against the bureaucratic and engineering status quo, and Arcata won in the end. But with the wetlands now almost 40 years old and losing their capacity to treat the ever-increasing volume of sewage, Arcata once again finds itself up against an “engineered” solution versus the original treatment wetlands now rich in native biodiversity.

As an ecologist, it is painful to read Chapter 7, “The United States of Vanished Wetlands”, that documents the once great bounty and biodiversity of coastal and inland wetlands in America that were demonized for health reasons, hated because they could not be traversed, and deemed unproductive until drained. *The Marsh Builders* details what early colonizers faced in America and describes how society’s perception of wetlands, disease, and pollution have changed over time. The once Great Black Swamp, a wetland over 4000 km² in size, was a major impediment for people moving westward and seen as a breeding zone for mosquitos until it was drained and converted to farmland. Today, flooding and non-point sources of agricultural pollution causing toxic algal blooms in rivers and lakes have society revisiting their relationship with the Black Swamp, with calls to return 10% of the landscape to wetland.

The Marsh Builders also documents the introduction and rise of new exotic diseases associated with wetlands, such as malaria and yellow fever, which were brought to America with colonization. When science identified mosquitos as the insect vector for these diseases, government in its bid to protect citizens institutionalized the draining of wetlands and in the 1940s promoted the use of organochlorine pesticides such as DDT. Few drained wetlands are restored today, but fortunately where habitat is available wildlife is recovering following a ban on the use of DDT in 1972.

The last chapter of the book, “The Fight This Time”, highlights the fact that, while it is well known that non-point sources of pollution (mainly from agriculture) cause over 75% of rivers and lakes to fail water quality standards, the CWA exempts farmers from their standards. And the momentum building in the EPA to regulate non-point sources of pollution has been derailed by Scott Pruitt, appointed by President Trump to head the EPA. While writing this review, I learned that Pruitt resigned as head of the EPA in December 2018. He will be replaced by Andrew Wheeler, a former coal lobbyist, dramatically highlighting the continuing saga of the tension between science, politics, and the world we choose to live in. *The Marsh Builders* is probably not the best title for the book, but that shouldn’t stop you from reading this excellent account of our relationship with water and wetlands over the past 200 years by veteran science journalist Sharon Levy.

BRENT TEGLER

Liana Environmental Consulting Ltd., Fergus, ON, Canada

NEW TITLES

Prepared by Barry Cottam

Please note: Only books marked † or * have been received from publishers. All other titles are listed as books of potential interest to subscribers. Please send notice of new books—or copies for review—to the Book Review Editor.

†Available for review *Assigned

Currency Codes: CAD Canadian Dollars, USD US Dollars, EUR Euros, AUD Australian Dollars, GBP British Pound.

BOTANY

The Grasses of Florida. By David W. Hall. 2019. University Press of Florida. 528 pages, 80.00 USD, Cloth.

Managing the Wild: Stories of People and Plants and Tropical Forests. By Charles M. Peters. 2018. Yale University Press. 208 pages, 30.00 USD, Cloth.

The Natural History of Flowers. By Michael Fogden and Patricia Fogden. 2018. Texas A&M University Press. 232 pages, 37.00 USD, Cloth. Also available as an E-book.

Unnatural Texas? The Invasive Species Dilemma. By Robin W. Doughty and Matt Warnock Turner. 2019. Texas A&M University Press. 272 pages, 32.00 USD, Cloth.

ENTOMOLOGY

Bedbug. By Klaus Reinhardt. 2018. Reaktion Books. Distributed by University of Chicago Press. 192 pages, 19.95 USD, 12.95 GBP, Paper.

The Biota of Canada – A Biodiversity Assessment. Part 1: The Terrestrial Arthropods. By David W. Langor and Cory Sheffield. 2019. ZooKeys, Issue 819. 520 pages, 99.00 GBP, Paper. Open access at <https://zookeys.pensoft.net/issue/1251/>.

Cerambycidae (Coleoptera) of Canada and Alaska. By Yves Bousquet, Serge Laplante, H.E. James Hammond, and David W. Langor. 2017. Entosphinx. 300 pages, 180.00 EUR, Cloth.

Dragonfly Nymphs of North America: An Identification Guide. By Kenneth Tennessen. 2019. Springer. 588 pages and 936 illustrations, 279.99 USD, Cloth, 219.00 USD, E-book.

Edible Insects and Human Evolution. By Julie Lesnik. 2018. University Press of Florida. 208 pages, 79.95 USD, Cloth.

Innumerable Insects. By Michael S. Engel. Foreword by Tom Baione. 2018. American Museum of Natural

History and Sterling Publishing. 232 pages, 27.95 USD, Cloth.

Never Home Alone: From Microbes to Millipedes, Camel Crickets, and Honeybees, the Natural History of Where We Live. By Rob Dunn. 2018. Basic Books. 336 pages, 36.50 CAD, Cloth, 23.99 CAD, E-book.

Why Every Fly Counts: A Documentation about the Value and Endangerment of Insects. Fascinating Life Sciences Series. By Hans-Dietrich Reckhaus. 2017. Springer. 111 pages, 39.99 USD, Cloth.

Underbug: An Obsessive Tale of Termites and Technology. By Lisa Margonelli. 2018. Scientific American/Farrar, Straus and Giroux. 320 pages, 27.00 USD, Cloth, 16.00 USD, Paper, 13.99 USD, E-book.

HERPETOLOGY

Cane Toad Wars. By Rick Shine. Foreword by Harry W. Greene. 2018. University of California Press. 288 pages, 34.95 USD, Cloth or E-book.

†**Ecology and Conservation of the Diamond-Backed Terrapin.** Edited by Willem M. Roosenburg and Victor S. Kennedy. 2019. Johns Hopkins University Press. 296 pages, 79.95 USD, Cloth or E-book.

Turtles in Trouble: The World's 25+ Most Endangered Tortoises and Freshwater Turtles – 2018. Presented by the Turtle Conservation Coalition. 2018. Turtle Conservancy. 84 pages, 10.00 USD, Cloth. Free PDF available at <http://www.iucn-tftsg.org/turtles-in-trouble-2018/>.

ICHTHYOLOGY

Atlantic Cod: A Bio-Ecology. Edited by George Rose. 2019. Wiley-Blackwell. 416 pages, 219.99 CAD, Cloth, 175.99 CAD, E-book.

Fishes of the Western North Atlantic. Memoir I: Sears Foundation for Marine Research. Volumes

1–10. 2018. Yale University Press. Various pagination, 75.00 USD each, Paper.

The Life of the Lakes: A Guide to the Great Lakes Fishery. Fourth Edition. By Brandon C. Schroeder, Dan M. O’Keefe, and Shari L. Dann. 2019. University of Michigan Press. 136 pages, 19.95 USD, Paper.

ORNITHOLOGY

Birds of Saskatchewan. Manley Callin Series No. 8. By Alan R. Smith, C. Stuart Houston, and J. Frank Roy. 2019. Nature Saskatchewan. 768 pages, 79.95 CAD, Cloth.

A Fieldworker’s Guide to the Golden Eagle. By Dave Walker. 2017. Whittles Publishing. 248 pages and 16-page colour section, 19.99 GBP, Paper, 13.99 GBP, E-book.

Long Hops: Making Sense of Bird Migration. By Mark Denny. 2016. University of Hawaii Press. 256 pages, 65.00 USD, Cloth, 29.99 USD, Paper.

The Population Ecology and Conservation of Charadrius Plovers. Edited by Mark A. Colwell and Susan M. Haig. 2019. CRC Press (Taylor & Francis Group). 336 pages, 149.95 USD, Cloth.

Taking Flight: A History of Birds and People in the Heart of America. By Mark Edmonds. 2018. Wisconsin Historical Society Press. 304 pages, 28.95 USD, Paper. Also available as an E-book.

Shorebirds in Action: An Introduction to Waders and their Behaviour. By Richard Chandler. 2017. Whittles Publishing. 256 pages and 440 colour illustrations, 21.95 GBP, Paper.

ZOOLOGY

The First Domestication: How Wolves and Humans Coevolved. By Raymond Pierotti and Brandy R. Fogg. 2017. Yale University Press. 344 pages, 38.00 USD, Cloth.

End of the Megafauna: The Fate of The World’s Hugest, Fiercest, and Strangest Animals. By Ross D.E. MacPhee. Illustrated by Peter Schouten. 2018. W.W. Norton. 256 pages, 35.00 USD, Cloth.

†**Mama’s Last Hug: Animal and Human Emotions.** By Frans de Waal. 2019. W.W. Norton. 336 pages, 36.95 USD, Paper.

Pandas to Penguins: Ethical Encounters with Animals at Risk. By Melissa Gaskill. 2018. Texas A&M University Press. 256 pages, 28.00 USD, Flexbound. Also available as an E-book.

***Return of the Wolf: Conflict & Coexistence.** By Paula Wild. 2018. Douglas & McIntyre. 272 pages, 32.95 CAD, Cloth.

Why Big Fierce Animals Are Rare: An Ecologist’s Perspective. By Paul A. Colinvaux. With a new foreword by Cristina Eisenberg. 2018. Princeton University Press. 272 pages, 18.95 USD, Paper. First published in 1979.

The Wisdom of Wolves: Lessons from the Sawtooth Pack. By Jim Dutcher and Jamie Dutcher. Foreword by Marc Bekoff. 2018. National Geographic Society. 224 pages, 26.00 USD, Cloth.

OTHER

***A Year on the Wild Side: A West Coast Naturalist’s Almanac.** By Briony Penn. 2019. TouchWood Editions. 400 pages, 26.00 CAD, Cloth.

Abundant Earth: Toward an Ecological Civilization. By Eileen Crist. 2019. University of Chicago Press. 288 pages, 105.00 USD, Cloth, 35.00 USD, Paper. Also available as an E-book.

The Art of Naming. By Michael Ohl. Translated by Elisabeth Lauffer. 2018. MIT Press. 312 pages, 29.95 USD, Cloth.

Big Lonely Doug. By Harley Rustad. 2018. House of Anansi Press, Walrus Books. 328 pages, 22.95 CAD, Paper.

The Birth of the Anthropocene. By Jeremy Davies. 2018. University of California Press. 248 pages, 29.95 USD, Cloth, 27.95 USD, Paper or E-book.

The Boatman: Henry David Thoreau’s River Years. By Robert M. Thorson. 2019. Harvard University Press. 336 pages, 17.95 USD, Paper.

Bombs Away: Militarization, Conservation, and Ecological Restoration. By David G. Havlick. 2018. University of Chicago Press. 208 pages, 35.00 USD, Cloth. Also available as an E-book.

Collecting the World: Hans Sloane and the Origins of the British Museum. By James Delbourgo. 2019. Harvard University Press – Belknap Press. 544 pages, 18.95 USD, Paper.

***Darwin Comes to Town: How the Urban Jungle Drives Evolution.** By Menno Schilthuizen. 2018. Picador. 304 pages, 27.00 USD, Cloth.

The Demon in the Machine: How Hidden Webs of Information Are Finally Solving the Mystery of Life. By Paul Davies. 2019. Allen Lane. 272 pages, 42.95 CAD, Cloth.

Discerning Experts: The Practices of Scientific Assessment for Environmental Policy. By Michael Op-

penheimer, Naomi Oreskes, Dale Jamieson, Keynyn Brysse, Jessica O'Reilly, Matthew Shindell, and Milena Wazeck. 2019. University of Chicago Press. 304 pages, 90.00 USD, Cloth, 35.00 USD, Paper or E-book

Ecology and Power in the Age of Empire: Europe and the Transformation of the Tropical World. By Corey Ross. 2017. Oxford University Press. 512 pages, 61.00 CAD, Cloth. Also available as an E-book.

The Evolving Animal Orchestra: In Search of What Makes Us Musical. By Henkjan Honing. Translated by Sherry MacDonald. 2019. MIT Press. 160 pages, 27.95 USD, Cloth.

Extreme Conservation: Life at the Edges of the World. By Joel Berger. 2018. University of Chicago Press. 368 pages, 30.00 USD, Cloth, 18.50 USD, E-book.

Dreamers, Visionaries, and Revolutionaries in the Life Sciences. Edited by Oren Harman and Michael R. Dietrich. 2018. University of Chicago Press. 336 pages, 120.00 USD, Cloth, 40.00 USD, Paper. Also available as an E-book.

Drawn to the Deep. The Remarkable Underwater Explorations of Wes Skiles. By Julie Hauserman. 2018. University Press of Florida. 256 pages, 24.95 USD, Cloth.

Enlivenment: Toward a Poetics for the Anthropocene. Untimely Meditations Series. By Andreas Weber. 2019. MIT Press. 208 pages, 15.95 USD, Paper.

The Epochs of Nature. By Georges-Louis Leclerc, le comte de Buffon. Translated and edited by Jan Zalasiewicz, Anne-Sophie Milon, and Mateusz Zalasiewicz. Introduction by Jan Zalasiewicz, Sverker Sörlin, Libby Robin, and Jacques Grinevald. 2018. University of Chicago Press. 288 pages, 45.00 USD, Cloth. Also available as an E-book. First published in 1778.

Fire in California's Ecosystems. Second Edition. Edited by Jan W. van Wagtendonk, Neil G. Sugihara, Scott L. Stephens, Andrea E. Thode, Kevin E. Shaffer, and Jo Ann Fites-Kaufman. Foreword by James K. Agee. 2018. University of California Press. 568 pages, 120.00 USD, Cloth or E-book.

Georg Forster: Voyager, Naturalist, Revolutionary. By Jurgen Goldstein. 2019. University of Chicago Press. 240 pages, 45.00 USD, Cloth or E-book.

***The Great Himalayan National Park: The Struggle to Save the Western Himalayas.** By Anthony J. Gaston and Sanjeeva Pandey. 2019. Niyogi Books. 364 pages, 280 colour pictures, and 15 maps, 52.20 CAD, Cloth.

Imagining Extinction: The Cultural Meanings of Endangered Species. By Ursula K. Heise. 2016. 288 pages, 82.50 USD, Cloth, 27.50 USD, Paper. Also available as an E-book.

Levelling the Lake: Transboundary Resource Management in the Lake of the Woods Watershed. By Jamie Benidickson. 2019. University of British Columbia Press. 367 pages, 89.95 CAD, Cloth.

Magnetic North: Sea Voyage to Svalbard Wayfarer. By Jenna Butler. 2018. University of Alberta Press. 120 pages, 19.99 CAD / USD, Paper or PDF.

Marine Historical Ecology in Conservation: Applying the Past to Manage for the Future. Edited by J.N. Kittinger, L.M. McClenachan, K.B. Gedan, and L.K. Blight. 2014. University of California Press. 312 pages, 45.00 USD, Cloth. Also available as an E-book.

Moths, Myths, & Mosquitoes. The Eccentric Life of Harrison G. Dyar, Jr. By Marc E. Epstein. 2016. Oxford University Press. 360 pages, 42.95 CAD, Cloth. Also available as an E-book.

Nonsense on Stilts: How to Tell Science from Bunk. Second Edition. By Massimo Pigliucci. 2018. University of Chicago Press. 336 pages, 22.50 USD, Paper. Also available as an E-book.

Serendipity: An Ecologist's Quest to Understand Nature. By James A. Estes. Foreword by Harry W. Greene. 2016. University of California Press. 256 pages, 29.95 USD, Cloth or E-book

The Secret Wisdom of Nature: Trees, Animals, and the Extraordinary Balance of All Living Things – Stories from Science and Observation. Third volume in The Mysteries of Nature Trilogy. By Peter Wohlleben. Translated by Jane Billingham. 2019. Greystone Books. 272 pages, 29.95 CAD, Cloth.

A Theory of Global Biodiversity (MPB-60). By Boris Worm and Derek P. Tittensor. 2018. Princeton University Press. 232 pages, 49.95 USD, Cloth or E-book.

Wildlife and Wind Farms – Conflicts and Solutions. Volume 1, Onshore: Potential Effects. Edited by Martin Perrow. 2017. Pelagic Publishing. 298 pages, 40.00 GBP, 69.06 CAD, Paper.

Wildlife and Wind Farms – Conflicts and Solutions. Volume 2, Onshore: Monitoring and Mitigation. Edited by Martin Perrow. 2017. Pelagic Publishing. 227 pages, 40.00 GBP, 69.06 CAD, Paper.

Wildlife and Wind Farms – Conflicts and Solutions, Volume 3. Offshore: Potential Effects. 2019. Edited by Martin Perrow. 2019. Pelagic Publishing. 301 pages, 45.00 GBP, 77.69 CAD, Paper.

Woodland Survey Handbook: Collecting Data for Conservation in British Woodland. By Keith Kirby and Jeanette Hall. 2019. Pelagic Publishing. 220 pages, 30.00 GBP, 51.79 CAD, Paper.

News and Comment

Upcoming Meetings and Workshops

Eastern Bird Banding Association Annual Meeting

The 96th annual meeting of the Eastern Bird Banding Association to be held 12–14 April 2019 in Roch-

ester, New York. Registration is currently open. More information is available at <https://ebba2019.com/>.

Northeast Natural History Conference

The 19th Northeast Natural History Conference to be held 12–14 April 2019 at the Sheraton Springfield Hotel, Springfield, Massachusetts. Registration is current-

ly open. More information is available at https://www.eaglehill.us/NENHC_2019/NENHC2019.shtml.

Northeast Fish & Wildlife Conference

The 75th annual Northeast Fish & Wildlife Conference, hosted by the Connecticut Department of Energy & Environmental Protection, to be held 14–16 April

2019 at the Mystic Marriott Hotel, Groton, Connecticut. Registration is currently open. More information is available at <https://www.neafwa.org/conference.html>.

Entomological Society of America, Southwestern Branch Meeting

The 67th annual meeting of the Southwestern Branch of the Entomological Society of America to be held 14–18 April 2019 at the Hyatt Regency Tulsa, Tulsa, Okla-

homa. Registration is currently open. More information is available at <https://www.entsoc.org/southwestern/2019-branch-meeting>.

Canadian Society of Zoology Annual Meeting

The annual meeting of the Canadian Society of Zoology to be held 13–17 May 2019 at the St. Clair College Centre of the Arts, Windsor, Ontario. Registration is

currently open. More information is available at <https://csz-scz2019.com/>.

Society for Freshwater Science Annual Meeting

The annual meeting of the Society for Freshwater Science to be held 19–23 May 2019 at the Salt Palace Convention Center, Salt Lake City, Utah. Regis-

tration is currently open. More information is available at <https://sfsannualmeeting.org/>.

Society of Wetland Scientists' Annual Meeting

The Society of Wetland Scientists' Annual Meeting to be held 28–31 May 2019 at the Hilton Baltimore, Baltimore, Maryland. The theme of the conference is: 'The Role of Wetlands in Meeting Global Environmen-

tal Challenges: Linking Wetland Science, Policy, and Society'. Registration is currently open. More information is available at <https://www.swsannualmeeting.org/>.

International Urban Wildlife Conference

The International Urban Wildlife Conference to be held 2–5 June 2019 at Portland State University, Portland, Oregon. The theme of the conference is: 'Collab-

oration & Conservation: Applications to Urban Wildlife'. Registration is currently open. More information is available at <http://www.urban-wildlife.org/>.

Conference on Great Lakes Research

The 62nd annual Conference on Great Lakes Research, hosted by The College at Brockport, to be held 10–14 June 2019 at The College at Brockport, State University of New York, Brockport, New York. The

theme of the conference is: 'Large Lakes Research: Connecting People and Ideas'. Registration is currently open. More information is available at <http://iaglr.org/iaglr2019/>.

North American Moose Conference & Workshop

The 53rd annual North American Moose Conference & Workshop to be held 10–14 June 2019 at the Sugarloaf Resort, Carrabassett Valley, Maine. Registra-

tion is currently open. More information is available at <https://www.namoose19.com/>.

Phycological Society of America Annual Meeting

The annual meeting of the Phycological Society of America to be held 23–27 June 2019 at the Hollywood Beach Marriott, Fort Lauderdale, Florida. Registra-

tion is currently open. More information is available at <https://www.psaalgae.org/meetings/2019/6/27/psa-2019-annual-meeting>.

American Ornithology 2019

The 137th annual meeting of American Ornithology and the 3rd annual meeting of the American Ornithological Society to be held 24–28 June 2019 at the William A. Egan Civic and Convention Center, Anchorage,

Alaska. The theme of the conference is: ‘Birds on the Edge: Dynamic Boundaries’. Registration is currently open. More information is available at <https://amornithmeeting.org/>.

American Society of Mammalogists Annual Meeting

The Centennial Celebration and 99th annual meeting of the American Society of Mammalogists to be held 28 June–2 July 2019 at the Hyatt Regency Washington,

Washington, DC. Registration is currently open. More information is available at <https://www.mammalmeetings.org/>.

Release of Flora of Newfoundland and Labrador webpage

A comprehensive treatment of the vascular flora of Newfoundland and Labrador was posted online by Susan J. Meades and William J. Meades in late 2018: <https://newfoundland-labradorflora.ca>. It is based on the authors’ decades of experience on “The Rock”, as well as the borrowed expertise of other local and “From Away” field botanists. All species, subspecific taxa, and named hybrids known from here are listed and a statement on their status is provided. Technical descriptions of some taxa are included with the expectation, over time, of providing this feature for all species in the *Flora*. Keys to the species of all major families are includ-

ed as are exhaustive enumerations of synonyms. The latter may seem out of place in a regional study but the complex taxonomic history of this area’s flora—particularly in light of the prolific taxonomic publication of “splitters” like M.L. Fernald and associations in the early 20th Century—make this a valuable addition. This independently supported, constantly updating floristic resource will be of great value to all field botanists active or interested in this area.

DANIEL F. BRUNTON
Ottawa, ON, Canada

Editors’ Report for Volume 131 (2017)

Mailing dates for the four issues in volume 131 are as follows: 30 August 2017, 1 December 2017, 28 June 2018, and 11 April 2018. Summaries of the distribution of memberships in the Ottawa Field-Naturalists’ Club, who all receive access to *The Canadian Field-Naturalist*, and subscribers to *The Canadian Field-Naturalist* for 2017 are provided in Table 1, along with comparison numbers for volume 130. Institutional subscribers potentially represent many thousands of users. The number of articles published in volume 131 declined over the number published in volume 130 but the number of notes remained about the same (Table 2); birds and mammals were the main subject areas (Table 2). A new type of manuscript, thematic collections, began to be published in 2017; these are editor-selected compilations of previously-published contributions in both *The Canadian Field-Naturalist* and the regional Ottawa Field-Naturalists’ Club publication, *Trail & Landscape*, on a central theme. The number of book reviews and new titles published in volume 131 more than doubled and tripled, respectively, over the numbers in volume 130 (Table 3). The total number of pages published increased slightly for volume 131 over volume 130 (Table 4), with articles and notes contributing most to the page count although there was a decrease in the number of pages for articles as would be expected with six fewer articles being published (Table 2).

A number of new initiatives began with volume 131 in addition to the thematic collections. Beginning with issue 1, *The Canadian Field-Naturalist* had digital object identifiers (DOIs) automatically assigned to all published content via the Online Journal System. The DOI is a global system that provides a persistent link for digital content to a location on the internet. This system requires that all references cited within a manuscript also are identified with a DOI (providing they have one). Many older issues of *The Canadian Field-Naturalist* do not have DOIs but, to promote all previously published content in *The Canadian Field-Naturalist* available through the Biodiversity Heritage Library (BHL), the URL web address for each is added to the reference. All volumes of *The Canadian Field-Natural-*

TABLE 2. Number of research articles and notes published in *The Canadian Field-Naturalist*, volume 131 (volume 130), by major field of study. Two thematic collections, one on alvars in Canada and the other on documenting species new to Canada, also were published in volume 131.

Subject	Articles	Notes	Total
Mammals	3 (9)	8 (10)	11 (19)
Birds	10 (4)	6 (5)	16 (9)
Amphibians and Reptiles	3 (4)	2 (0)	5 (4)
Fishes	1 (4)	2 (2)	3 (6)
Plants	3 (4)	2 (1)	5 (5)
Insects	1 (2)	0 (0)	1 (2)
Non-insect Invertebrates	2 (3)	1 (2)	3 (5)
Other	1 (0)	0 (0)	1 (0)
Total	24 (30)	21 (20)	45 (50)

TABLE 3. Number of reviews and new titles published in the Book Review section of *The Canadian Field-Naturalist*, volume 131 (volume 130), by topic.

	Reviews	New Titles
Zoology	15 (10)	155 (45)
Botany	7 (3)	43 (16)
Miscellaneous	18 (9)	111 (32)
Total	40 (22)	309 (93)

ist more than six years old are freely available through the BHL. All URLs and DOIs also are made active in the online version of each article, by inserting an embedded hyperlink taking the online reader directly to the related publication or website.

The other new initiatives recognized historic field naturalists and awarded current publications. Beginning in issue 3 and as part of Canada’s 150th birthday celebration in 2017, a section was added to the News and Comments to formally recognize Canada’s greatest field naturalists. The first two Greatest Canadian Field-Naturalists were James Fletcher and John Macoun. A new award for the best paper published in the current volume of *The Canadian Field-Naturalist*, the James Fletcher Award, also was established in the same issue

TABLE 1. The 2017 (2016) circulation of *The Canadian Field-Naturalist*. Compiled by Eleanor Zurbrigg from the subscription list for 131(4).

Subscriber Type	Canada	USA	Other	Total
OFNC Members	51 (58)	4 (3)	0 (1)	55 (62)
Subscriptions:				
Individual	26 (21)	7 (6)	0 (1)	33 (28)
Institutional	73 (84)	106 (116)	12 (13)	191 (213)
Total	150 (163)	117 (125)	12 (15)	279 (303)

TABLE 4. Number of pages per section published in *The Canadian Field-Naturalist*, volume 131 (130), by issue.

	Issue				Total
	1	2	3	4	
Editorials/Editors' Report	0 (0)	0 (3)	2 (0)	1 (0)	3 (3)
Articles	67 (63)	47 (73)	47 (43)	42 (59)	203 (238)
Notes	7 (18)	17 (14)	30 (14)	27 (21)	81 (67)
Thematic Collections	5 (–)	8 (–)	0 (–)	0 (–)	13 (–)
Tributes	0 (0)	0 (0)	0 (0)	0 (18)	0 (18)
Book Reviews*	14 (8)	15 (4)	15 (9)	13 (11)	57 (32)
News and Comment†	2 (1)	1 (2)	6† (3)	12 (4)	21 (10)
Reports‡	19 (0)	0 (4)	0 (15)	0 (0)	19 (19)
Erratum	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Index	– (–)	– (–)	– (–)	9 (7)	9 (7)
Total	114 (90)	88 (100)	100 (84)	104 (120)	406 (394)

*Includes reviews and new titles.

†Includes Greatest Canadian Field-naturalists and announcement of James Fletcher Award.

‡Includes Annual Business Meeting Minutes, Annual Committee Reports, Financial Statements, and Awards.

of volume 131; all these are available at <https://doi.org/10.22621/cfn.v131i3.2071>.

Fifty-seven manuscripts were submitted to *The Canadian Field-Naturalist* in 2017, 12 fewer than in 2016; all were submitted using the Online Journal System, some after an initial email submission. Ten of the 59 were for a Special Issue, “Studies on Canadian Amphibians and Reptiles in Honour of Dr. Francis Cook”, scheduled for publication in 2018; one of those submitted in 2017 for the Special Issue was withdrawn because the author had insufficient time for revision and another did not make the revision deadline for the Special Issue. Only six of the 57 submitted manuscripts were not accepted for publication upon initial submission or review and one was withdrawn meaning 89.5% were accepted or undergoing revision. In 2016, 82.6% of the 69 submissions were accepted for publication and either published or undergoing further revision and review. A total of 24 articles, 21 notes, and two thematic collections were published in 2017 (Table 2).

Dwayne Lepitzki was *Editor-in-Chief* for volume 131 while Amanda Martin, the *Assistant Editor*, edited content, proofread galleys, and sent and received author order and transfer of copyright forms. Sandra Garland and John Wilmshurst proof-read and copy-edited manuscripts. Wendy Cotie typeset galleys, provided corrections for page proofs, and created pdfs. Barry Cottam requested books for review, selected reviewers, edited submitted reviews, and prepared the new titles listings. Ken Young continued with the tasks of managing subscriptions, page charge invoices, and budget tracking although Eleanor Zurbrigg assumed the duties of managing subscriptions in the summer of 2017. William Halliday, Online Journal Manager and Webmaster, provided digital content to subscribers, posted tables of contents, abstracts, and pdfs on *The Canadian Field-Naturalist* website, and prepared the Index. Our Associate Editors managed manuscripts, provided reviews

and recommendations, and guided authors through the revision process. The Publication Committee, chaired by Jeff Saarela and consisting of Annie Bélair, Dan Brunton, Carolyn Callaghan, Paul Catling, Barry Cottam, William Halliday, Diane Kitching, Dwayne Lepitzki, Amanda Martin, Karen McLachlan Hamilton, Frank Pope, David Seburn, and Eleanor Zurbrigg effectively guided the operation of the journal. We are indebted to our very dedicated team.

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DWAYNE LEPITZKI, *Editor-in-Chief*

AMANDA MARTIN, *Assistant Editor*

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COVER: Wingless Mountain Grasshopper (*Booneacris glacialis*) near Amherst, Nova Scotia. See the article in this issue by John Klymko *et al.*, pages 319–329. Records from 1967 and 2016 confirm the presence of this native species in the province. Photo: John Klymko, 13 September 2016.

Orthoptera and allies in the Maritime provinces, Canada: new records and updated provincial checklists

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Abstract

We provide an updated checklist of Orthoptera and their allies for each Maritime province of Canada with details for 21 new species records. Drumming Katydid (*Meconema thalassinum*), recorded from Nova Scotia (NS) and Prince Edward Island (PEI), and Sprinkled Grasshopper (*Chloealtis conspersa*), recorded from New Brunswick (NB) are reported for the first time from the Maritimes as a whole. We report range extensions in the Maritime region for Australian Cockroach (*Periplaneta australasiae*; NB), Treetop Bush Katydid (*Scudderia fasciata*; NS), Short-legged Camel Cricket (*Ceuthophilus brevipes*; PEI), Spotted Camel Cricket (*Ceuthophilus maculatus*; PEI), Roesel's Shield-backed Katydid (*Roeseliana roesellii*; NS), and Black-horned Tree Cricket (*Oecanthus nigricornis*; PEI). Short-winged Mole Cricket (*Neoscapteriscus abbreviatus*; NB) and European Mole Cricket (*Gryllotalpa gryllotalpa*; NS) are reported as adventives (non-native species that are believed to be not yet established), new to Canada from the Maritimes. Other new records for species not known to be established are Lined Earwig (*Doru taeniatum*; NS), Australian Cockroach (*Periplaneta australasiae*; PEI), American Cockroach (*Periplaneta americana*; NB), Brown Cockroach (*Periplaneta brunnea*; PEI), Smooth Cockroach (*Nyctibora laevigata*; NB), West Indian Leaf Cockroach (*Blaberus discoidalis*; NB), an unidentified *Parcoblatta* species (NB), Brown-banded Cockroach (*Supella longipalpa*; PEI), Praying Mantis (*Mantis religiosa*; NB), and American Bird Grasshopper (*Schistocerca americana*; NS).

Key words: Orthopteroid; Orthoptera; Dermaptera; Blattodea; Mantodea; Maritime provinces; new species; range extensions

Introduction

A comprehensive treatment of Canada's Orthoptera and allies (orthopteroids), including Canadian range maps for all reported species, was published in 1985 (Vickery and Kevan 1985). This was quickly followed by an update of the Canadian fauna with provincial-level checklists (Vickery and Scudder 1987). Since then, reports of new orthopteroid records for the Maritime provinces have appeared in several publications, most notably Catling *et al.* (2013) with ten new provincial records. Other recent reports include Chandler (1992), Catling *et al.* (2009), McAlpine (2009), Scudder and Vickery (2010), McAlpine and Ogden (2012), Clements *et al.* (2013), and McAlpine *et al.* (2015).

In this paper, we add to this growing body of work with 21 new provincial records and provide updated provincial checklists to reflect the additions since 1987.

Although only species with an extant or previously established population should be considered part of the region's fauna, we follow Vickery and Scudder (1987) and report non-native species that have been collected in a jurisdiction but are not believed to be established there. These are adventive species and include intercepts taken from shipped goods and vehicles.

Vouchers reported here have been deposited in the New Brunswick Museum (NBM, with accession number indicated), the Atlantic Forestry Centre (AFC), the Université de Moncton (UDM), the Nova Scotia Museum (NSM), the Nova Scotia Department of Natural Resources collection at Shubenacadie (NSNR), the private collection of J.B.O. (JBO), and Agriculture and Agri-food Canada, Charlottetown (AACC). Common names are from CESCC (2016), except where mentioned in Table 1.

A contribution towards the cost of this publication has been provided by the Thomas Manning Memorial Fund of the Ottawa Field-Naturalists' Club.

TABLE 1. Orthoptera and allies (Orthopteroids) in the Maritime provinces of Canada: New Brunswick (NB), Prince Edward Island (PEI), and Nova Scotia (NS).

Order	Family	Subfamily	Species*	Common name†	Occurrence‡			
					NB	PEI	NS	
Dermaptera	Spongiphoridae Forficulidae	Labiinae Forficulinae	<i>Labia minor</i> (L. 1758)	Lesser Earwig	N		N	
			<i>Forficula auricularia</i> L. 1758	European Earwig	N-9	N-6	N	
Mantodea	Mantidae	Mantinae	<i>Doru taeniatum</i> (Dohrn 1862)	Lined Earwig	A-6		A-11	
			<i>Mantis religiosa</i> (L. 1758)	Praying Mantis	A/N-11		A/N-4	
Blattodea	Blattidae	Blattinae		Oriental Cockroach			N	
			<i>Blatta orientalis</i> L. 1758	American Cockroach	A/N-11		N	
			<i>Periplaneta americana</i> (L. 1758)	Australian Cockroach	N-11	A/N-11	N	
			<i>Periplaneta australasiae</i> (Fabricius 1775)					
			<i>Periplaneta brunnea</i> Burmeister 1838	Brown Cockroach		A/N-11	N-4	
			<i>Nyctibora laevigata</i> (Beauvois 1805)	Smooth Cockroach ^a	A-11		A	
			<i>Eurycotis floridana</i> (Walker 1868)	Skunk Cockroach ^a				
			<i>Blaberus discoidalis</i> Serville 1839	West Indian Leaf Cockroach ^a	A-11		A	
			<i>Panchlora nivea</i> (L. 1758)	Green Banana Cockroach ^a	A		A	
			<i>Rhyparobia maderae</i> (Fabricius 1781)	Madeira Cockroach ^a	A		A	
			<i>Colapteroblatta nigra</i> (Brunner von Wattenwyl 1892)	Round-backed Cockroach ^a				
			<i>Supella longipalpa</i> (Fabricius 1798)	Brown-banded Cockroach		A/N-11	N-4	
			<i>Blattella germanica</i> (L. 1767)	German Cockroach	N	N	N	
			<i>Ectobius lapponicus</i> (L. 1758)	Dusky Cockroach	N-7	N-1	N-7	
			<i>Ceuthophilus brevipes</i> Scudder 1862	Short-legged Camel Cricket	X	X-11	X	
			<i>Ceuthophilus guttulatus</i> Walker 1869	Speckled Camel Cricket			X	
			<i>Ceuthophilus maculatus</i> (Harris 1841)	Spotted Camel Cricket	X	X-11	X	
			<i>Scudderia curvicauda</i> (De Geer 1773)	Curve-tailed Bush Katydid	X	X	X	
			<i>Scudderia fasciata</i> (Beutenmüller 1894)	Treetop Bush Katydid	X-10		X-11	
			<i>Scudderia furcata</i> Brunner von Wattenwyl 1878	Fork-tailed Bush Katydid	X-8	X-6	X	
			<i>Scudderia pistillata</i> Brunner von Wattenwyl 1878	Broad-winged Bush Katydid	X	X-6	X	
			<i>Scudderia septentrionalis</i> (Serville 1839)	Northern Bush Katydid	X-10			
			<i>Roeseliana roeselii</i> (Hagenbach 1822)	Roesel's Shield-backed Katydid	N-3		N-11	
			<i>Conocephalus brevipennis</i> (Scudder 1862)	Short-winged Meadow Katydid	X-5			
			<i>Conocephalus fasciatus</i> (De Geer 1773)	Slender Meadow Katydid	X	X	X	
			<i>Neoconocephalus ensiger</i> (Harris 1841)	Sword-bearing Conehead Katydid	X		N	
			<i>Neoconocephalus retusus</i> (Scudder 1878)	Round-tipped Conehead Katydid			V-2	
			<i>Orchelimum gladiator</i> Bruner 1891	Gladiator Meadow Katydid	X-6	X-5		
			<i>Meconema thalassinum</i> (De Geer 1773)	Drumming Katydid		N-11	N-11	
			<i>Gryllotalpa gryllotalpa</i> (L. 1758)	European Mole Cricket ^b			A-11	
			<i>Neoscapteriscus abbreviatus</i> (Scudder 1869)	Short-winged Mole Cricket ^b	A-11			
			<i>Acheta domesticus</i> (L. 1758)	House Cricket		N	N	
			<i>Gryllus pennsylvanicus</i> Burmeister 1838	Fall Field Cricket	X	X	X	
			<i>Allonemobius allardi</i> (Alexander and Thomas 1959)	Allard's Ground Cricket	X		X	

TABLE 1. (continued)

Order	Family	Subfamily	Species*	Common name†	Occurrence‡			
					NB	PEI	NS	
Acrididae	Oecanthinae	Cyrtacanthacridinae	<i>Allonemobius fasciatus</i> (De Geer 1773)	Striped Ground Cricket	X	X	X	
			<i>Eunemobius carolinus</i> (Scudder 1877)	Carolina Ground Cricket	X	X	X	
			<i>Neonemobius palustris</i> (Blatchley 1900)	Sphagnum Ground Cricket	X-5		X	
			<i>Oecanthus nigricornis</i> Walker 1869	Black-horned Tree Cricket	X-4	X-11	X-5	
			<i>Schistocerca nitens</i> (Thunberg 1815)	Gray Bird Grasshopper ^b			A	
			<i>Schistocerca americana</i> (Drury 1773)	American Bird Grasshopper			A-11	
			<i>Booneacris glacialis</i> (Scudder 1863)	Wingless Mountain Grasshopper	X	X	X	
			<i>Melanoplus bivittatus</i> (Say 1825)	Two-striped Grasshopper	X	X	X	
			<i>Melanoplus borealis</i> (Fieber 1853)	Northern Grasshopper	X	X	X	
			<i>Melanoplus fasciatus</i> (Walker 1870)	Huckleberry Grasshopper	X	X	X	
	Melanoplinae		<i>Melanoplus femurrubrum</i> (De Geer 1773)	Red-legged Grasshopper	X	X	X	
			<i>Melanoplus keeleri</i> Thomas 1874	Keeler's Grasshopper	X		X	
			<i>Melanoplus punctulatus</i> (Scudder 1862)	Grizzly Grasshopper	X-6			
			<i>Melanoplus sanguinipes</i> (Fabricius 1798)	Migratory Grasshopper	X	X	X	
			<i>Melanoplus stonei</i> Rehn 1904	Stone's Grasshopper	X	X-6		
			<i>Camnula pellucida</i> (Scudder 1862)	Clear-winged Grasshopper	X	X	X	
			<i>Chortophaga viridifasciata</i> (De Geer 1773)	Green-striped Grasshopper	X	X-6	X	
			<i>Dissosteira carolina</i> (L. 1758)	Carolina Grasshopper	X	X	X	
			<i>Pardalophora apiculata</i> (Harris 1835)	Coral-winged Grasshopper	X			
	Oedipodinae		<i>Spharagemon bolli</i> Scudder 1875	Boll's Grasshopper	X-6			
			<i>Trimerotropis verruculata</i> (Kirby 1837)	Crackling Grasshopper	X	X	X	
			<i>Stethophyma gracile</i> (Scudder 1862)	Graceful Sedge Grasshopper	X	X	X	
			<i>Stethophyma lineatum</i> (Scudder 1862)	Striped Sedge Grasshopper	X	X	X	
			<i>Chloealtis conspersa</i> (Harris 1841)	Sprinkled Grasshopper	X-11			
			<i>Pseudochorthippus curtipennis</i> (Harris 1835)	Marsh Meadow Grasshopper	X	X	X	
			<i>Orphulella speciosa</i> (Scudder 1862)	Pasture Slant-faced Grasshopper	X			
			<i>Nomotettix cristatus</i> (Scudder 1862)	Crested Pygmy Grasshopper	X	X	X	
			<i>Tetrix arenosa</i> Burmeister 1838	Obscure Pygmy Grasshopper	X		X	
	Tetrigidae	Tetriginae	<i>Tetrix brunneri</i> (Bolivar 1877)	Brunner's Pygmy Grasshopper	X		X	
			<i>Tetrix ornata</i> (Say 1824)	Ornated Pygmy Grasshopper	X	X	X	
			<i>Tetrix subulata</i> (L. 1761)	Granulated Pygmy Grasshopper	X	X	X	
			<i>Tettigidea lateralis</i> (Say 1824)	Black-sided Pygmy Grasshopper	X		X	
	Gomphocerinae							
	Batrachideinae							

*Dermaptera, Mantodea, Blattodea, and Orthoptera names follow Hopkins *et al.* (2017), Otte *et al.* (2017), Beccaloni (2014), and Cigliano *et al.* (n.d.), respectively.
†Common names are from CESCC (2016), except where indicated with superscripts: a. Beccaloni (2014), b. Cigliano *et al.* (n.d.).
‡A = adventive, a non-native species that has been reported from, but not become established in a region; A/N = questionable adventive, used for non-native species when it is not clear whether it has become established; N = non-native, established; V = vagrant, present only as transients away from the species' normal range; X = native. The justification for the occurrences can be found in Vickery and Kevan (1985) and Vickery and Scudder (1987), and in the following citations, noted after the type of occurrence: 1. Chandler (1992); 2. Catling *et al.* (2009); 3. McAlpine (2009); 4. Scudder and Vickery (2010); 5. McAlpine and Ogden (2012); 6. Catling *et al.* (2013); 7. Clements *et al.* (2013); 8. McAlpine *et al.* (2015); 9. Tournear (2017); 10. Lewis and McAlpine (2018); 11. Klymko *et al.* (current article).

New Provincial Records

DERMAPTERA

FORFICULIDAE

Forficulinae

Doru taeniatum (Dohrn 1862), Lined Earwig — **Nova Scotia**: Colchester County: Truro, 4 September 1991, T.D. Smith (NSNR).

Presumably this is an adventive occurrence. This earwig is considered adventive in New Brunswick (NB) and Ontario (ON), the only other provinces where this species has been reported (Vickery and Scudder 1987; Catling *et al.* 2013).

MANTODEA

MANTIDAE

Mantinae

Mantis religiosa (L. 1758), Praying Mantis — **New Brunswick**: Saint John County: Saint John, August 1979 (NBM-44584); Westmorland County: Moncton, 2 September 1994, "Terry M." (UDM).

It is unclear if *M. religiosa* is established anywhere in the Maritimes, despite attempts made to introduce the species in Atlantic Canada (Vickery and Kevan 1985). The species has been taken recently in the Annapolis Valley, Nova Scotia (NS), but it is unclear if a sustaining population exists there (Scudder and Vickery 2010). The NB specimens are likely from releases and not established populations.

BLATTODEA

BLATTIDAE

Blattinae

Periplaneta americana (L. 1758), American Cockroach — **New Brunswick**: Saint John County: Saint John, 10 June 1902, W. McIntosh (NBM-30126), 29 August 1980, in shipment (NBM-31836); York County: Fredericton, [no date], C.C. Smith (AFC); Nashwaaksis IGA, "Bananas imported", 21 March 1967 (AFC); Restigouche County: Dalhousie, "ex. auto from Cuba", 8 August 1966 (AFC).

This cosmopolitan species has been found in buildings across Canada, but there are no previous records for NB (Vickery and Kevan 1985; Vickery and Scudder 1987). It is not known if the 1902 Saint John record and undated Fredericton record represent adventive occurrences or established populations.

Periplaneta brunnea Burmeister, 1838, Brown Cockroach — **Prince Edward Island**: Prince County: O'Leary, "Packed in with Bananas", 1992, J.G. Stewart (AACC); Queens County: Charlottetown, "Found in apt.", 15 April 1991, J.G. Stewart (AACC); Kings County: Souris, December 1985, L.S. Thompson (AACC).

In Canada, *P. brunnea* is often considered an adventive species (Vickery and Scudder 1987), although Scudder and Vickery (2010) report that it has become

established, at least temporarily, in NS. In Prince Edward Island (PEI), the O'Leary record appears to have been an interception of insects on imported goods; it is not known if established colonies existed at Charlottetown or Souris.

Periplaneta australasiae (Fabricius 1775), Australian Cockroach — **Prince Edward Island**: Queens County: Charlottetown, January 1986, L.S. Thompson (AACC); 1988, F. Legault (AACC). **New Brunswick**: Westmorland County: Sackville, Mount Allison Campus, Flemington Building, 45.9001°N, 64.3726°W, 9 March 2017, found dead, N.A. Donaher, J. Klymko (NBM-53103), 17 May 2017, found alive, P.J. Cormier, J. Klymko (NBM-53104).

This exotic species is established at Mount Allison University in Sackville, NB, and has been since at least 2006 when J.K. saw a live individual. It is not known if this species is established in PEI. It has been considered established elsewhere in Canada, including NS (Vickery and Kevan 1985; Vickery and Scudder 1987).

BLABERIDAE

Blaberinae

Blaberus discoidalis Serville 1839, West Indian Leaf Cockroach — **New Brunswick**: Saint John County: Saint John, 28 April 1981, found in fruit shipment in grocery store, C. Bree (NBM-30033; Figure 1).

In Canada, this species occurs in greenhouses and has been used in laboratory study (Vickery and Kevan



FIGURE 1. West Indian Leaf Cockroach (*Blaberus discoidalis*). Specimen in New Brunswick Museum. Collected in Saint John, New Brunswick, in late April 1981 by C. Bree. Photo: P.M. Catling in 2011.

1985). The only previous occurrence in Canada was in Quebec (QC) where it was reared in laboratories (Vickery and Scudder 1987). The Saint John specimen is presumably an intercept. The species is widespread in the Greater Antilles and northern South America (Rehn and Hebard 1927), where many Canadian fruit imports originate.

ECTOBIIDAE

Blattellinae

Parcoblatta sp. — **New Brunswick**: Kings County: Clifton Royal, October 1992, R. Perry, abundant in trailer from southeastern USA (NBM-52790).

The only specimen available is a female, which is morphologically unidentifiable to the species level. We attempted species-level identification with DNA barcoding; however, several attempts at polymerase chain reaction amplification were unsuccessful. The specimen presumably originated in the southeastern United States of America (USA), where eight *Parcoblatta* species occur (Beccaloni 2014). No *Parcoblatta* species have been reported from the Maritimes, although *P. pennsylvanica*, *P. virginica*, *P. uhleriana*, and *P. caudelli* have been reported elsewhere in Canada (Vickery and Scudder 1987).

Nyctiborinae

Nyctibora laevigata (Beauvois 1805), Smooth Cockroach — **New Brunswick**: Saint John County: Saint

John, 30 June 1900, P.R. McIntosh (NBM-31837; Figure 2).

This species is native to the Caribbean and perhaps Panama, and it has been reported as an adventive in the USA, Canada, and Europe (Gutiérrez and Pérez-Gelabert 2000). In Canada, it has been recorded in ON and QC (Vickery and Scudder 1987). We assume that the Saint John specimen was intercepted.

Pseudophyllodromiinae

Supella longipalpa (Fabricius 1798), Brown-banded Cockroach — **Prince Edward Island**: Queens County: Charlottetown, “Found in home, family from Ontario”, March 1986, L.S. Thompson (AACC).

It can be inferred from the label that the Charlottetown specimen was part of an adventive population. In Newfoundland and Labrador it is considered adventive (Vickery and Scudder 1987) whereas in NS and several more western provinces it is considered established (Scudder and Vickery 2010). Where it occurs in Canada, it is domiciliary (Vickery and Kevan 1985).

ORTHOPTERA

RHAPHIDOPHORIDAE

Ceuthophilinae

Ceuthophilus brevipes (Scudder 1862), Short-legged Camel Cricket — **Prince Edward Island**: Queens County: Uigg, MacPhail Woods Ecological Project, pit-



FIGURE 2. Smooth Cockroach (*Nyctibora laevigata*). Specimen in New Brunswick Museum. Collected in Saint John, New Brunswick, on 30 June 1900 by P.R. McIntosh. Photo: D.F. McAlpine in 2018.

fall trap, 46.1594°N, 62.8213°W, 24 August, 2 September 2015, N.D. Brown (NBM-53087, 53088).

This northeastern flightless species was expected on PEI; it is also known from other islands including Newfoundland, Anticosti Island, and Cape Breton (Vickery and Kevan 1985).

Ceuthophilus maculatus (Harris 1841), Spotted Camel Cricket — **Prince Edward Island**: Queens County: Rice Point, December 1982, “found in Fulton’s basement”, L.S. Thompson (AACC); Donagh, 46.26029°N, 62.97452°W, July 2016, J.D. McAskill (NBM-53089).

Vickery and Kevan (1985) note that the species is sometimes found in cellars, as is the case for the earliest PEI record. The record from Donagh is from a natural forest habitat. Unlike *C. brevipes*, *C. maculatus* is not known from other major Canadian islands, such as Newfoundland, Anticosti Island, and Cape Breton (Vickery and Kevan 1985).

TETTIGONIIDAE

Phaneropterinae

Scudderia fasciata (Beutenmüller 1894), Treetop Bush Katydid — **Nova Scotia**: Cumberland County: 1.1 km southwest of Mosleys Pond, open spruce (*Picea* spp.) forest with Eastern White Pine (*Pinus strobus* L.), swept from heather (*Ericaceae*) understorey, 45.9135°N, 64.0984°W, 13 September 2016, J.K. (NBM-53094).

Scudderia fasciata was first reported from the Maritimes based on NB records by Lewis and McAlpine

(2018). Our NS record, and additional NB records reported below under Other Notable Records, demonstrate how widespread the species is. *Scudderia fasciata* is associated with treetops, especially those of conifers (Himmelman 2009), where it would be out of sight of collectors. Perhaps that is the reason that this large species eluded detection in the Maritimes in the past.

Tettigoniinae

Roeseliana roeselii (Hagenbach 1822), Roesel’s Shield-backed Katydid — **Nova Scotia**: Colchester County: Five Islands Provincial Park, swept from small wet meadow, 45.4058°N, 64.0221°W, 13 August 2016, J.B.O. (JBO; Figure 3).

This exotic species was first documented in North America at Montréal, QC, in 1952 (Urquhart and Beaudry 1953). Since that time, it has become established through much of the northeast, including NB (McAlpine 2009; Catling *et al.* 2013), and its spread into other Maritime provinces was anticipated (McAlpine and Ogden 2012).

Meconematinae

Meconema thalassinum (De Geer 1773), Drumming Katydid — **Prince Edward Island**: Prince County: Borden-Carleton, flower garden, 46.2548°N, 63.6954°W, 18 September 2013, J.K. and S.L.R. (NBM-46201); Queens County: Brackley Beach, PEI National Park,



FIGURE 3. Roesel’s Shield-backed Katydid (*Roeseliana roeselii*). Specimen in the private collection of J.B.O. Collected in Five Islands Provincial Park, Nova Scotia, on 13 August 2016 by J.B. Ogden. Photo: J.B. Ogden in 2018.

inside park entrance kiosk, 46.4277°N, 63.1997°W, 16 August 2016, D.J. Terstege (photo record, see www.inaturalist.org/observations/3901605); Tea Hill, on window screens at house, 46.2033°N, 63.0571°W, 18 August 2016, 19 August 2016, A.Y. Laurin (photo records, see www.inaturalist.org/observations/5419927, www.inaturalist.org/observations/5419996); Mount Stewart, Allisary Creek, 46.3703°N, 62.8494°W, 20 August 2016, R.W.H. (NBM-53090); Stanhope, PEI National Park, attracted to light at campground, 46.4217°N, 63.1106°W, 27 August 2016, R.W.H. (photo record, see <https://www.inaturalist.org/observations/4000961>); Mount Stewart, under canopy at gas station, 46.3672°N, 62.8751°W, 19 September 2016, R.W.H. (NBM-53091);

Cavendish, attracted to lights at campground, 46.4841°N, 63.3653°W, 28 July 2017, J.B.O. and N. Ogden (NSNR); Kings County: Summerville, attracted to light, 46.2110°N, 62.7301°W, 30 August 2015, 2 September 2015, R.W.H. (Figure 4); **Nova Scotia**: Halifax County: Halifax, Victoria Park, 44.6410°N, 63.5796°W, 29 August 2016, S.L.R. (NBM-53092); Dartmouth, Elliot Street, 44.6707°N, 63.5602°W, 2 September 2016, S.L.R. (NBM-53093).

Meconema thalassinum, which is native to Europe, was first reported in North America in 1960 from Long Island, New York, where it had been established since at least 1957 (Gurney 1960a,b). Since then, records have been published for New York State (Sismondo 1978;

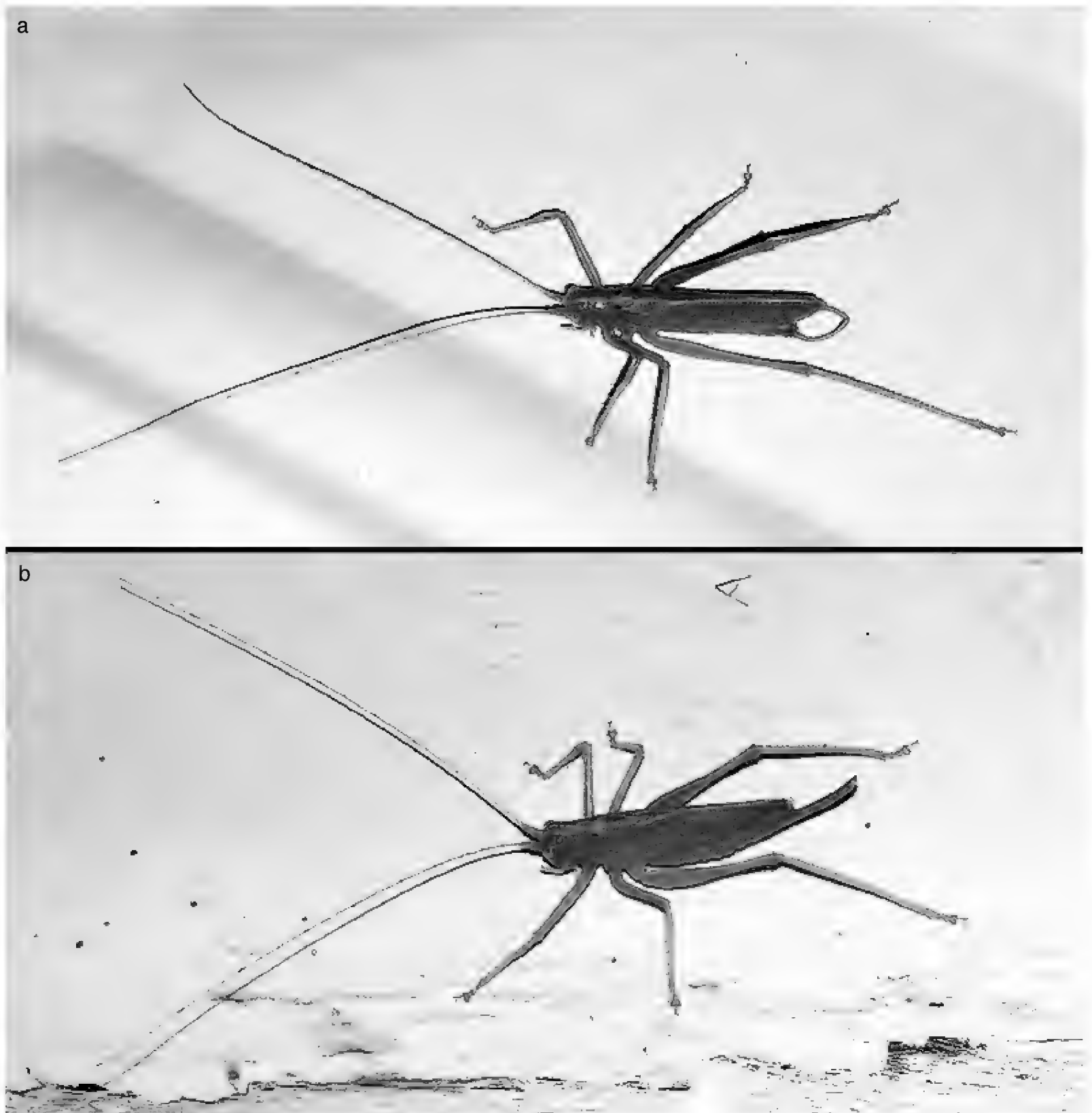


FIGURE 4. Drumming Katydid (*Meconema thalassinum*) at Summerville, Prince Edward Island. a. Male (30 August 2015). b. Female (2 September 2015). Photos: R.W. Harding.

Hoebeke 1981), Rhode Island (Hoebeke 1981), Michigan (Bland 2003), ON (Marshall *et al.* 2004), Connecticut (Maier 2005), British Columbia and Washington (Cannings *et al.* 2007), and Massachusetts (Himmelman 2009). Although it has not been reported for PEI in the primary literature, records were documented in Nature PEI's newsletter (Harding 2017). The closest known record to the Maritimes is at Mount Desert Island, Maine (2012 photo record by B. Woo, see bugguide.net/node/view/681733). The number of locations known for this species in PEI suggests that it has been established there for some time.

GRYLLOTALPIDAE

Gryllotalpinae

Neoscapteriscus abbreviatus Scudder 1869, Short-winged Mole Cricket — **New Brunswick**: Kings County: Grand Bay-Westfield, 45.3171°N, 66.2018°W, 25 October 1991, in home, family recently moved from Oakville, Ontario, D.F.M. (NBM-52789).

This South American native has been established in Florida since 1899 (Walker and Nickle 1981). The NB specimen was likely transported north in horticultural material, either to ON then NB, as the label suggests is possible, or directly to NB. The species has not previously been reported from Canada.

Gryllotalpa gryllotalpa (L. 1758), European Mole Cricket — **Nova Scotia**: Halifax County: Sackville, in delicatessen, 17 October 1988, G. MacLellan (NSM).

This Palaearctic species is established in New Jersey, New York, Massachusetts, and possibly Florida, and it has been recorded as an intercept in Pennsylvania (Nickle and Castner 1984). Why the NS specimen was found in such an odd circumstance is unclear, but, like *Neoscapteriscus abbreviatus*, it may have been brought into the Maritimes in horticultural material. It has not previously been reported from Canada.

GRYLLIDAE

Oecanthinae

Oecanthus nigricornis Walker 1869, Black-horned Tree Cricket — **Prince Edward Island**: Kings County: Murray Harbour, Thomas Island, 46.0275°N, 62.5069°W, 1 September 2015, M.A. Arsenault (NBM-53096); Summerville, attracted to light, 46.2110°N, 62.7301°W, 19 September 2015, 20 September 2015, R.W.H. (photo records, see Harding 2016); Queens County: Mount Stewart, Allisary Creek, 46.3703°N, 62.8494°W, 27 August 2016, R.W.H. (NBM-53097).

Although it has not been reported in the primary literature, a PEI record was documented in Nature PEI's newsletter (Harding 2016). This Nearctic species, known from southern ON, southern QC, and much of the eastern USA (Capinera *et al.* 2004), was noticed in NB by naturalists in about 1990 or earlier, and, by the early 2000s, it was known to be widespread across southern NB (McAlpine and Ogden 2012). That this species, now common in the Maritimes, was not report-

ed in historical works (e.g., Vickery *et al.* 1974; Vickery and Kevan 1985) suggests that it may have colonized the area recently.

ACRIDIDAE

Cyrtacanthacridinae

Schistocerca americana (Drury 1770), American Bird Grasshopper — **Nova Scotia**: Halifax County: intercepted in vegetables originally from USA, 17 July 1983 (NSM); Lake Echo, flew in window, April 2008, L. MacDonald (NSM).

This species has a core range in the southeastern USA and much of Latin America. It is known to be a long-distance migrant, with presumed migrants reaching southern ON and Massachusetts (Vickery and Kevan 1985). It has also been recorded from numerous locations as an intercept, and it is assumed that the Lake Echo record was inadvertently carried in from elsewhere, given how early in the season it was recorded.

Gomphocerinae

Chloealtis conspersa (Harris 1841), Sprinkled Grasshopper — **New Brunswick**: Northumberland County: Portage Island, 47.1566°N, 65.03745°W, 6 August 2015, J.K. (NBM-53099); Charlotte County: Mill Cove Creek, Campobello Island, salt marsh, net sweeping, 44.9274°N, 66.9108°W, 26 September 2016, D.F.M. (NBM-52791).

This species was expected in NB and the Maritimes. Vickery and Kevan (1985) map a record from the area of Calais, Maine, which is adjacent to the NB border and close to the Charlotte County, NB, record.

Other Notable Records

ORTHOPTERA

Tettigoniidae

Phaneropterinae

Scudderia fasciata (Beutenmüller 1894), Treetop Bush Katydid — **New Brunswick**: York County: Fredericton, 26 September 2008, C.I.G.A. (photo record, see bugguide.net/node/view/228908); Kent County: Kouchibouguac National Park, 14 September 2012, D.A.D. (Figure 5).

Lewis and McAlpine (2018) reported the first Maritimes records of *S. fasciata* based on specimens collected in NB in 2013 and 2017. The photographic records reported here represent earlier NB records.

ACRIDIDAE

Melanoplinae

Booneacris glacialis (Scudder 1863), Wingless Mountain Grasshopper — **Nova Scotia**: Halifax County: Caribou Bog, NE of Dartmouth, 1967, P. Ward (NSM); Cumberland County: Amherst, 900 m south of Mosleys Pond, treed bog, 45.9126°N, 64.0924°W, 13 September 2016, J.K. (NBM-53101; Figure 6).



FIGURE 5. Treetop Bush Katydid (*Scudderia fasciata*), in Kouchibouguac National Park, New Brunswick, 14 September 2012. Photo: D.A. Doucet.



FIGURE 6. Wingless Mountain Grasshopper (*Booneacris glacialis*), near Amherst, Nova Scotia, 13 September 2016. Photo: J. Klymko.

Vickery (1961) reports that specimens taken in Shelburne County, NS, by C.E. Atwood had been misplaced at the Royal Ontario Museum. The species is listed as “X?” for NS in Vickery and Scudder’s (1987) Canadian checklist. The X is notation given to native species, and

the question mark either means they doubted the veracity of the record, or they doubt the species persists in the province. No other specimens had been found in NS despite many attempts to recapture the species, as reported by Vickery *et al.* (1974). The 1967 and 2016 records

confirm the species' presence in NS. *Booneacris glacialis* was also listed as "X?" for PEI in Vickery and Scudder's (1987) Canadian checklist, presumably because surveys to relocate the only known colony, one reported by Walker (1915) from Dundee, have proven unsuccessful (see Vickery *et al.* 1974).

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The spiders of Prince Edward Island: experts and citizen scientists collaborate for faunistics

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Abstract

Although lists of spider species have been compiled for all of Canada's provinces and territories, the spider fauna of Prince Edward Island (PEI) is poorly known. Based on the efforts of citizen scientists, naturalists, and scientists on PEI and researchers at the Centre for Biodiversity Genomics, we present the first comprehensive list of spider species on the island, increasing the known number from 44 to 198. The Centre for Biodiversity Genomics conducted intensive collection in Prince Edward Island National Park; Nature PEI citizen scientists and naturalists contributed specimens from across the island from several different habitats. This provincial list is dominated by the araneoid families, Linyphiidae, Theridiidae, and Araneidae, with 55, 27, and 22 species, respectively. Several non-native species, such as the theridiid Eurasian False Black Widow Spider (*Steatoda bipunctata* (L.)) and the araneid Red-sided Sector Spider (*Zygiella atrica* (C.L. Koch)), have been collected in several locations on the island, suggesting that they are well established. This work highlights the effectiveness of collaboration among citizen scientists, naturalists, and professional researchers to further our knowledge of species diversity and distributions.

Key words: Maritime provinces; Araneae; Prince Edward Island; PEI; faunistics; citizen science; Arachnida

Introduction

Faunistic studies provide crucial biodiversity information and help accumulate the species distribution, habitat use, and relative abundance data necessary for conservation. Furthermore, faunistic studies record introduced species and their potential establishment as well as the movement of native species into new habitats or geographic areas over time. In several areas of the world, including Canada, the distribution of some species groups is poorly known. Obtaining a faunal baseline for a region is important because it allows tracking of future changes in species composition. Such temporal data are valuable in determining changes in, and relative abundances of, local species assemblages including decline or even extirpations of native species caused by, for example, climate change, the introduction and establishment of non-native species, or direct human alteration of landscapes and habitat (Shochat *et al.* 2004).

Spiders are a ubiquitous, diverse group, with about 47 000 species described worldwide (World Spider Cat-

alog 2018). Spider species lists and preliminary conservation status assessments have recently been compiled for all Canadian provinces and territories (CESCC 2016). Some provinces and one territory—British Columbia (Bennett *et al.* 2017), Yukon (Dondale *et al.* 1997), Manitoba (Aitchison-Benell and Dondale 1990), Quebec (Paquin and Dupérré 2003), and Newfoundland and Labrador (Pickavance and Dondale 2005; Perry *et al.* 2014)—have produced peer-reviewed or otherwise expert-created lists (e.g., online resources). Less comprehensive (but still useful) lists, resulting from habitat or area-specific ecological or faunistic studies, are available for Nova Scotia (Dondale 1956), Alberta (Buddle 2001; Holmberg and Buckle 2002), Ontario (Dondale 1971; Dondale and Redner 1994), Saskatchewan (Doane and Dondale 1979), New Brunswick (Boiteau 1983), Nunavut (Leech 1966; Pickavance 2006), and Northwest Territories (Working Group on General Status of NWT Species 2016).

Before the work reported here, no dedicated spider faunistics or ecological studies had occurred on Prince

Edward Island (PEI), and the spiders of the island appeared to be the most poorly known of the Canadian provinces and territories. To our knowledge, most of the 44 recorded species for PEI (Paquin *et al.* 2010; CESSC 2016) are a result of casual collecting by visiting entomologists/arachnologists or dedicated surveys focussed on documenting the distribution of a particular species (e.g., Knysh and Giberson 2012). In comparison, despite Nunavut's remoteness and small human population, it has at least 96 species of spiders (Pickavance 2006; CESSC 2016), and Nova Scotia and New Brunswick, the provinces bordering PEI, have 446 and 390 known species, respectively (Paquin *et al.* 2010; CESSC 2016).

Citizen science, the engagement of citizens to aid in the collection and/or processing of scientific data (Silvertown 2009), allows scientists to leverage the data acquisition power of the public (e.g., Prudic *et al.* 2017). This is particularly relevant in the context of faunistics because obtaining sufficient specimens to provide good coverage for a particular province (or over other broad spatial scales) could be a daunting task without the help of numerous volunteers (Acorn 2017).

PEI, which is approximately 5660 km² in area and lies on the east coast of Canada in the Gulf of St. Lawrence, is the smallest and most densely populated province (Statistics Canada 2016). Approximately 14 km of water separates PEI from the mainland (New Brunswick and Nova Scotia), and the adjacent ocean heavily influences the temperate climate. PEI generally has warmer winters and cooler summers than the nearby mainland, with average annual temperatures for January and July (1981–2010) of $-7 \pm 2.3^{\circ}\text{C}$ (mean \pm SD) and $19 \pm 1.2^{\circ}\text{C}$, respectively (ECCC 2017). In winter, PEI is surrounded by sea-ice that contributes to long, cool springs, while warming of the shallow Gulf of St. Lawrence in summer results in lengthy, mild autumns.

About 75% of the land is under 45 m elevation (Loo and Ives 2003). The province is over 90% privately owned (Statistics Canada 2016) and has a long history of land alteration and disturbance (Loo and Ives 2003; Sobey and Glen 2004). Most of the original Acadian Forest was cleared for agriculture by European settlers beginning in 1723, and, by 1900, an estimated 70% of the island was cleared (Loo and Ives 2003). Regenerated forest on former agricultural land and remaining fragments of original forest show a high degree of disturbance (Loo and Ives 2003; Sobey and Glen 2004). Forests currently make up 44% of the total area, active agriculture 38%, abandoned farmland 4%, while wetlands (6%) and coastal sand dunes (1%) are relatively rare habitats (Statistics Canada 2016).

Recently, a DNA barcoding project conducted by the Centre for Biodiversity Genomics (CBG) increased the number of spider species known from PEI to 82 (Blagoev *et al.* 2016). Most of the new records were produced after the data compilation that resulted in the

most recent wild species report from the Canadian Endangered Species Conservation Council (CESSC 2016). Building on that momentum, a project organized by Nature PEI involving numerous citizen scientists, in combination with experts, confirmed the presence of many of the previously documented species and further increased the list of spider species. Here we present the most comprehensive list of the 198 species now known to constitute the spider fauna of PEI.

Methods

Specimen collection and curation

In 2015, Nature PEI naturalists recruited volunteer citizen scientists to collect spiders from across PEI (Figure 1). Participants were given specific instructions via a training workshop and a field manual composed of a variety of papers and online resources (e.g., Martin 1977). The workshop described techniques for the selection of survey areas, collection and preservation of specimens, and recording and submission of field data on data cards. Specimen collection techniques consisted of pitfall trapping, sweep netting, foliage beating, aspiration, Berlese funnel extraction, and hand collecting. In total, 29 collectors (20 of whom were previously associated with Nature PEI) from across PEI contributed specimens.

Adult spiders were identified to species level by J.J.B., data-labelled, and stored in 80% ethanol in screw-cap vials with polyseal caps. A database of all specimens examined was created using Excel (Microsoft, Corp., Redmond, Washington, USA) and maintained by Nature PEI. Additional older specimens (<50) were supplied by the University of Prince Edward Island (UPEI) from beach collections and some sampling of other habitats, and are included in the Nature PEI survey. Specimens, excluding the UPEI beach specimens, have been deposited in the New Brunswick Museum in Saint John, New Brunswick (accession numbers: NBM-010790 to NBM-011349).

We compiled the list of species documented previously (i.e., Dondale and Redner 1978, 1982, 1990; Platnick and Dondale 1992; Dondale *et al.* 2003; Paquin *et al.* 2010) and, more recently by the CBG's DNA barcoding initiative (Blagoev *et al.* 2016) and CESSC (2016). We also searched (directly or via personal communication) the Canadian National Collection of Insects, Arachnids and Nematodes, New Brunswick Museum, Nova Scotia Museum of Natural History, UPEI, and Agriculture Canada collections in Charlottetown, but these yielded no additional records.

The CBG project used hand collecting, sieving, sweep netting, and trapping (Malaise, pan, pitfall, sticky) techniques at various sites along the trails of Prince Edward Island National Park, and one specimen was collected in Miscouche (Figure 1).

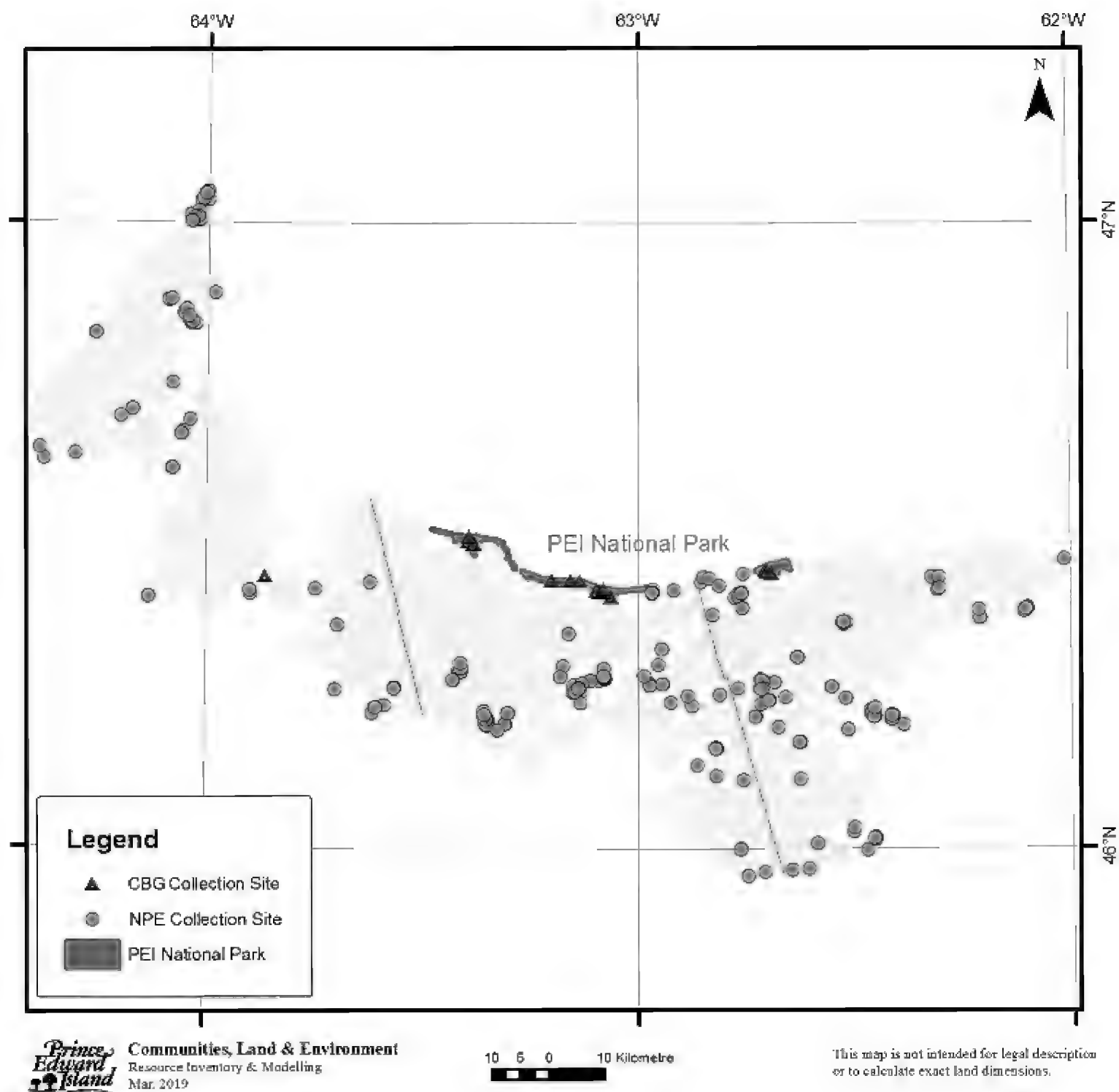


FIGURE 1. Spider collection sites on Prince Edward Island, Canada, in association with the efforts by the Centre for Biodiversity Genomics (CBG) and Nature PEI's citizen scientist campaign (NPE).

Nomenclature, specimen identification, habitat and locality data

Nomenclature follows the World Spider Catalog (2017); species are listed by family in alphabetical order. J.J.B. used various identification guides (e.g., Dondale and Redner 1978, 1990; Platnick and Dondale 1992; Dondale *et al.* 2003; Paquin and Dupérré 2003) and primary literature (e.g., Millidge 1983) to identify species and their preferred habitats. Specimens collected by the CBG were identified by G.A.B. using DNA barcoding and comparative morphology. Specimen data and photographs of barcoded specimens are available at the Barcode of Life Data System website (www.boldsystems.org; Ratnasingham and Hebert 2007).

Results

Before the CBG and Nature PEI activities, our literature, online, and museum searches yielded six other species records bringing the total to 44 species (Blagoev *et al.* 2016). More recent efforts by the CBG (G.A.B. unpubl. data) have added a further 69 new species many of which overlapped with the citizen science initiative reported here. The Nature PEI effort yielded 130 species from 737 adult specimens (over 4300 specimens collected in total). Barcode data recovered 82 species from Prince Edward Island National Park, of which 46 were new records for PEI. The complete list of spiders known to occur in PEI now comprises 198 species representing 20 families.

Some records, especially among the 44 known before Blagoev *et al.* (2016), have not been confirmed through barcoding or Nature PEI's initiative. These include Starbellied Orbweaver (*Acanthepeira stellata* (Walckenaer)), Sickie Big-headed Money Spider (*Baryphyma trifrons* (O. Pickard-Cambridge)), Autumn Money Spider (*Erigone autumnalis* Emerton), Maritime Patterned Money Spider (*Grammonota maritima* Emerton), Saxatile Thin-Legged Wolf Spider (*Pardosa saxatilis* (Hentz)), Common Pirate Wolf Spider (*Pirata piraticus* (Clerck)), and Punctate False Black Widow Spider (*Steatoda albomaculata* (De Geer)).

Nearly 10% (19 species) of the new records are non-native species. In comparison, only about 5% of all spider species recorded in Canada are introduced (Paquin *et al.* 2010; R.B. unpubl. data). Some of PEI's introduced species—e.g., Cross Orbweaver (*Araneus diadematus* Clerck), Zebra Jumping Spider (*Salticus scenicus* (Clerck)), Long-bodied Cellar Spider (*Pholcus phalangioides* (Fuesslin)), and Barn Funnelweaver (*Tegenaria domestica* (Clerck))—are cosmopolitan and synanthropic. None of the species recorded in this checklist is endemic to PEI.

Annotated list of species

Species are organized alphabetically by family, genera, and species. Data sources for physical specimens are indicated by NPE (Nature PEI), CBG (Centre for Biodiversity Genomics), or CNC (Canadian National Collection of Insects, Arachnids and Nematodes), with the NPE records solely due to NPE citizen scientist effort; otherwise literature records are indicated by reference (e.g., Dondale *et al.* 2003). Counties are indicated in bold followed by specific collection localities. Original 44 species (before NPE or CBG, i.e., 2015) are indicated as *. Probable records (R.B. pers. obs., cannot locate record) are indicated as † but not included in totals. Common names are from CESSC (2016). If the species is introduced, the origin is indicated; if native, the global range is stated (World Spider Catalog 2018).

AGELENIDAE (4 species)

Agelenopsis potteri (Blackwall, 1846) Nearctic
Common Grass Funnelweaver

Prince: Augustine Cove, Central Kildare, St. Nicholas, Norway; **Queens:** Bonshaw, Cavendish; Charlottetown, Dalvay, Marshfield St. Catherines, Orwell Cove; **Kings:** Abney, Brudenell, Cherry Island; Savage Harbour, Summerville

Habitat: Gardens, fields, and open forest, common around human dwellings

Data source: CBG, NPE

Agelenopsis utahana (Chamberlin & Ivie, 1933)

Northern Grass Funnelweaver Nearctic

Prince: Central Kildare; **Queens:** Brookvale, Charlottetown, Dalvay, Donagh, Wood Islands;

Kings: Brudenell, Forest Hill, Launching

Habitat: Gardens, fields, and open forest, common around human dwellings

Data source: CBG, NPE

Coras montanus (Emerton, 1890) Nearctic
Northern Spurred Woodland Spider

Prince: Augustine Cove

Habitat: Litter of mixed coniferous forest; under bark; in crevices between rocks

Data source: NPE

Tegenaria domestica (Clerck, 1758) Palearctic
Barn Funnelweaver (introduced)

Prince: North Tryon; **Queens:** Charlottetown, St. Catherines; **Kings:** Summerville

Habitat: Cool, dark, humid areas such as basements and sheds

Data source: NPE

AMAUROBIIDAE (2 species)

Callobius bennetti (Blackwall, 1846) Nearctic
Eastern Laceweaver

Kings: Greenwich

Habitat: Litter of mixed coniferous forest; under (shoreside) stones

Data source: CBG

Cybaeopsis euopla (Bishop & Crosby, 1935) Nearctic
Common Spined Laceweaver

Queens: Dalvay; **Kings:** Launching

Habitat: Litter of mixed coniferous forest

Data source: CBG, NPE

ARANEIDAE (22 species)

**Acanthepeira stellata* (Walckenaer, 1805)
Starbellied Orbweaver Nearctic

Unknown collection locality

Habitat: Deciduous trees and shrubs, in forage crops, and in tall grass and weeds

Data source: Dondale *et al.* 2003

Araneus corticarius (Emerton, 1884) Nearctic
Humped Bog Orbweaver

Prince: Portage; **Queens:** Marshfield; **Kings:** Launching

Habitat: Bogs and swamps

Data source: NPE

Araneus diadematus Clerck, 1757 Palearctic
Cross Orbweaver (introduced)

Prince: North Tryon; **Queens:** Bonshaw, Cavendish, Charlottetown, St. Catherines, Donagh; **Kings:** Georgetown Royalty, Summerville, Launching, High Bank, Thomas Island, West St. Peters

Habitat: Widespread, particularly common around human-made structures and gardens

Data source: CBG, NPE

Araneus groenlandicola (Strand, 1906) Nearctic
Northern Bog Orbweaver

Queens: Blooming Point

Habitat: Bogs, low shrubs, stunted trees

Data source: NPE

**Araneus marmoreus* Clerck, 1758 Holarctic
Marbled Orbweaver

Prince: Central Kildare, Freeland, North Tryon;

Queens: Donagh, Glenfinnan, Marshfield;

Kings: Launching

Habitat: Tall grasses/shrubs in marshes, sometimes moist open forest areas

Data source: Dondale *et al.* 2003, NPE

Araneus nordmanni (Thorell, 1870) Holarctic
Normann's Orbweaver

Queens: Bonshaw, Cavendish, Dalvay;

Kings: Brudenell, Summerville

Habitat: Mixed coniferous forest; trees and tall shrubs near forest

Data source: CBG, NPE

**Araneus saevus* (L. Koch, 1872) Holarctic
Common Orbweaver

Queens: Bonshaw

Habitat: Trunks and lower branches of trees, mixed coniferous forest

Data source: Dondale *et al.* 2003, NPE

Araneus trifolium (Hentz, 1847) Nearctic
Shamrock Orbweaver

Queens: Blooming Point, Dalvay, Donagh;

Kings: Greenwich, High Bank, Launching, Summerville, West St. Peters

Habitat: Tall shrubs and herbs

Data source: CBG, NPE

**Araniella displicata* (Hentz, 1847) Holarctic
Six-spotted Yellow Orbweaver

Queens: Cavendish, Dalvay; **Kings:** Greenwich, New Perth, Summerville

Habitat: Shrubs and herbs, deciduous trees, sometimes in conifers

Data source: Dondale *et al.* 2003, CBG, NPE

**Argiope aurantia* Lucas, 1833 Nearctic
Yellow Garden Orbweaver

Queens: Cavendish, Charlottetown, Donagh, Orwell Cove; **Kings:** St. Catherines, Summerville

Habitat: Open areas e.g., gardens, meadows, old fields, shrubs, tall grasses

Data source: CBG, NPE

**Argiope trifasciata* (Forsskål, 1775) Nearctic
Banded Garden Orbweaver

Prince: Central Kildare, North Cape, Norway, St. Nicholas; **Queens:** Blooming Point, Cavendish, Charlottetown, Donagh, Grandview; **Kings:** Summerville, West St. Peters

Habitat: Open areas e.g., gardens, meadows, old fields, shrubs, tall grasses

Data source: CBG, NPE

Cyclosa conica (Pallas, 1772) Holarctic
Common Trashline Orbweaver

Prince: Augustine Cove; **Queens:** Cavendish, Dalvay

Habitat: Shrubs and trees, mixed coniferous forest

Data source: CBG, NPE

Eustala cepina (Walckenaer, 1841) Nearctic
Riparian Duncap Orbweaver

Kings: Greenwich

Habitat: Grassland, marshes, dune plants, roadside weeds, and garden crops

Data source: CBG

Eustala emertoni (Banks, 1904) Nearctic
no common name

Queens: Dalvay

Habitat: Fields, open forests, and marshes

Data source: CBG

Eustala rosae Chamberlin & Ivie, 1935 Nearctic
no common name

Queens: Dalvay

Habitat: Fields, open forests, and marshes

Data source: CBG

**Hypsosinga pygmaea* (Sundevall, 1831) Holarctic
Common Dark-eyed Orbweaver

Queens: Blooming Point, Covehead; **Kings:** Greenwich

Habitat: Wet meadows, shrubs and herbs of forest edges and roadsides

Data source: Dondale *et al.* 2003, CBG, NPE

Hypsosinga rubens (Hentz, 1847) Nearctic
Forest Dark-eyed Orbweaver

Kings: Head of Cardigan

Habitat: Shrubs and herbs in forests, leaf litter and loose bark

Data source: NPE

**Larinioides cornutus* (Clerck, 1758) Holarctic
Furrow Orbweaver

Prince: North Tryon, Coleman, Norway; **Queens:** Bonshaw, Brookvale, Cavendish, Covehead, Dalvay, Donagh, Kellys Cross; **Kings:** Forest Hill, Head of Cardigan, Milltown Cross, Savage Harbour, Summerville

Habitat: Common on human-made structures (e.g., fences, buildings), hedges, and shrubs

Data source: CBG, NPE

Larinioides patagiatus (Clerck, 1758) Holarctic
Ornamental Orbweaver

Queens: Dalvay

Habitat: Common on human-made structures (e.g., fences, buildings), hedges, and shrubs, particularly near coniferous forest

Data source: CBG

Mangora placida (Hentz, 1847) Nearctic
Tuft-legged Orbweaver

Queens: Brackley Beach, Cavendish, **Kings:** Head of Cardigan

Habitat: Undergrowth of deciduous forests, but may also be found in tall grass

Data source: CBG, NPE

**Neoscona arabesca* (Walckenaer, 1841) Nearctic
Arabesque Orbweaver

Prince: Augustine Cove, Central Kildare; **Queens:** Blooming Point, Bonshaw, Covehead, Dalvay, Glenfinnan, Lake Verde, Marshfield, Mount Albion, South Melville, Wood Islands; **Kings:** Abney, Corraville, Forest Hill, Greenwich, High Bank, Launching, Little Sands, New Perth, Savage Harbour, St. Peters Harbour, Summerville

Habitat: Tall weeds and grasses

Data source: Dondale et al. 2003, CBG, NPE

**Zygiella atrica* (C.L. Koch, 1845) Palearctic
Red-sided Sector Spider (introduced)

Prince: Norway, North Tryon; **Queens:** Cavendish, Charlottetown, Covehead, Bonshaw, Donagh; **Kings:** Brudenell, Greenwich, Head of Cardigan, Launching, Savage Harbour, St. Catherines, Summerville

Habitat: Heath plants and boulders along coastlines, also on human-made structures (e.g., fences, barns, windows)

Data source: Dondale et al. 2003, CBG, NPE

CLUBIONIDAE (13 species)

Clubiona abboti Koch, 1866 Nearctic
Abbot's Sac Spider

Queens: Brackley Beach, Covehead, Dalvay;

Kings: Summerville

Habitat: Litter of forests and meadows, under stones, in bogs/wetlands

Data source: CBG, NPE

Clubiona bryantae Gertsch, 1941 Nearctic
Bryant's Sac Spider

Queens: Covehead; **Kings:** Corraville

Habitat: Litter from meadows, forest edges, litter from spruce-fir forests, herbaceous vegetation in bogs/swamps

Data source: CBG, NPE

**Clubiona canadensis* Emerton, 1890 Nearctic
Canada Harpoon Sac Spider

Prince: Norway; **Queens:** Bonshaw, Brackley Beach, Cavendish, Dalvay; **Kings:** Greenwich, Savage Harbour, Woodville Mills

Habitat: Trees and shrubs, under loose bark, under stones, in leaf litter and moss

Data source: Dondale and Redner 1982, CBG, NPE

Clubiona johnsoni Gertsch, 1941 Nearctic
Johnson's Sac Spider

Queens: Brackley Beach, Covehead

Habitat: On the ground of meadows, bogs, and forests, and from shrubs and beach litter

Data source: CBG

Clubiona kastoni Gertsch, 1941 Nearctic
Kaston's Sac Spider

Queens: Covehead

Habitat: Forest litter, on beaches and sand dunes, or on bogs

Data source: CBG

Clubiona kiowa Gertsch, 1941 Nearctic
Kiowa Sac Spider

Queens: Covehead

Habitat: Plant litter in marshes

Data source: CBG

Clubiona moesta Banks, 1896 Holarctic
Mournful Sac Spider

Queens: Dalvay

Habitat: Branches of trees, under loose bark, in hay-fields

Data source: CBG

Clubiona norvegica Strand, 1900 Holarctic
Norway Harpoon Sac Spider

Prince: Norway; **Queens:** Covehead

Habitat: In sphagnum bogs, beach grasses, and salt marshes, on buildings, rocky lake shores, at the margins of prairie sloughs, occasionally in foliage

Data source: CBG, NPE

Clubiona obesa Hentz, 1847 Nearctic
Trilobed Sac Spider

Queens: Cavendish

Habitat: Low-growing shrubs in deciduous forests, on trunks, and in tall grasses

Data source: CBG

Clubiona pallidula (Clerck, 1757) Palearctic
European Sac Spider (introduced)

Queens: Cavendish

Habitat: On shrubs, herbs, under bark

Data source: CBG

Clubiona quebecana Dondale & Redner, 1976
Quebec Sac Spider Nearctic

Queens: Dalvay

Habitat: Trunks and larger branches of deciduous trees such as oaks

Data source: CBG

**Clubiona riparia* L. Koch, 1866 Holarctic
Riparian Sac Spider

Prince: Coleman; **Queens:** Blooming Point, Charlottetown; **Kings:** St. Catherines, Summerville

Habitat: In tall grass in marshes and near sloughs and lakes, mixed forest on the ground

Data source: Dondale and Redner 1982, NPE

Clubiona trivialis C.L. Koch, 1843 Holarctic
Conifer Sac Spider

Queens: Marshfield; **Kings:** Launching, Savage Harbour, St. Catherines, Thomas Island

Habitat: Spruce, fir, and pine foliage, sphagnum bogs, low deciduous shrubs, and loose bark, stones, and leaf litter in mixed forests

Data source: NPE

DICTYNIDAE (9 species)

**Argenna obesa* Emerton, 1911 Nearctic
Short-eared Meshweaver

Queens: Covehead, Cavendish

Habitat: Wetland, river banks, moist forest clearings

Data source: CBG

Cicurina brevis (Emerton, 1890) Nearctic
Small-eared Meshweaver

Queens: Brackley Beach; **Kings:** Launching, Greenwich

Habitat: Mostly in forest, but also fields under rocks and in rotten logs, in litter

Data source: CBG, NPE

Dictyna bostoniensis Emerton, 1888 Nearctic
Boston Thread Meshweaver

Queens: Covehead

Habitat: Mixed forest; shrubs and herbs

Data source: CBG

Dictyna brevitarsa Emerton, 1915 Nearctic
Short-heeled Thread Meshweaver

Queens: Dalvay; **Kings:** Greenwich

Habitat: Mixed coniferous forest; shrubs and herbs

Data source: CBG

Dictyna volucripes Keyserling, 1881 Nearctic
Truncated Thread Meshweaver

Prince: North Cape, Norway; **Queens:** Brackley Beach

Habitat: Shrubs and vegetation in open fields, potentially forest clearings

Data source: CBG, NPE

Emblyna annulipes (Blackwall, 1846) Holarctic
Common Ribbon Meshweaver

Prince: West Point; **Queens:** Dalvay

Habitat: Mixed forest litter, on low vegetation and trees

Data source: CBG, NPE

Emblyna manitoba (Ivie, 1947) Nearctic
Manitoba Ribbon Meshweaver

Queens: Covehead

Habitat: Mixed forest, low vegetation

Data source: CBG

Emblyna phylax (Gertsch & Ivie, 1936) Nearctic
Grooved Ribbon Meshweaver

Queens: Bonshaw; **Kings:** Greenwich

Habitat: Mixed forest, litter, and low vegetation

Data source: CBG, NPE

Emblyna sublata (Hentz, 1850) Nearctic
Wide Ribbon Meshweaver

Kings: Summerville, Head of Cardigan

Habitat: Vegetation in fields, shrubs, apple orchards on trees

Data source: NPE

GNAPHOSIDAE (4 species)

**Gnaphosa parvula* Banks, 1896 Nearctic
Slender Ground Spider

Kings: Corraville

Habitat: Under stones, boards, and beach debris, in meadows and bogs

Data source: Platnick and Dondale 1992, NPE

**Herpyllus ecclesiasticus* Hentz, 1832 Nearctic
Parson Ground Spider

Queens: Dalvay; **Kings:** Summerville

Habitat: In buildings and under logs and stones, but also associated with deciduous trees, pine, and pitcher plants

Data source: CBG, NPE

Micaria pulicaria (Sundevall, 1831) Holarctic
Iridescent Antmimic Ground Spider

Queens: Donagh

Habitat: Fields, meadows, deciduous and mixed forests, bogs, and fens; on beaches and salt marshes; and in buildings

Data source: NPE

- **Zelotes fratrīs* Chamberlin, 1920 Holarctic
Common Preening Ground Spider
Queens: Covehead, Dalvay, Marshfield, Savage Harbour
Habitat: In litter of deciduous and coniferous forest, orchards, meadows, and in salt- and freshwater marshes
Data source: Platnick and Dondale 1992, CBG, NPE
- HAHNIIDAE (4 species)
Antistea brunnea (Emerton, 1909) Nearctic
Brown Comb-tailed Spider
Kings: Launching, New Zealand
Habitat: Wet areas in mixed forest
Data source: NPE
- Cryphoea montana* Emerton, 1909 Nearctic
Mountain Comb-tailed Spider
Queens: Dalvay
Habitat: Mixed coniferous forest; under bark; shrubs
Data source: CBG
- Neoantistea gosiuta* Gertsch, 1934 Nearctic
Goshute Comb-tailed Spider
Queens: Dalvay
Habitat: Mixed coniferous forest
Data source: CBG
- Neoantistea magna* (Keyserling, 1887) Nearctic
Thick-hooked Comb-tailed Spider
Queens: Bonshaw, Dalvay; **Kings:** New Zealand
Habitat: Mixed coniferous woods; back of beaches; bogs.
Data source: CBG, NPE
- LINYPHIIDAE (55 species)
Agyneta fabra (Keyserling, 1886) Nearctic
Double-knobbed Short-legged Sheetweaver
Queens: Cavendish, Dalvay
Habitat: Mixed forest litter
Data source: CBG
- Agyneta unimaculata* (Banks, 1892) Nearctic
One-spotted Short-legged Sheetweaver
Queens: Brackley Beach
Habitat: Mixed forest litter
Data source: CBG
- Allomengea dentisetis* (Grube, 1861) Holarctic
Toothed Tuft-horned Sheetweaver
Prince/Queens: Malpeque Bay
Habitat: Coastal barrens and near ponds on ground/low vegetation
Data source: CNC
- **Baryphyma trifrons* (O. Pickard-Cambridge, 1863)
Sickle Big-headed Money Spider Holarctic
Locality unavailable
Habitat: Low shrubs and litter, damp habitats
Data source: Unavailable
- Bathyphantes canadensis* (Emerton, 1882)
Canada Shield Sheetweaver Holarctic
Prince: Central Kildare
Habitat: Mixed forest litter
Data source: NPE
- Centromerus denticulatus* (Emerton, 1909) Nearctic
Toothy Spurred Sheetweaver
Queens: Dalvay
Habitat: Mixed forest litter
Data source: CBG
- Centromerus persolutus* (O. Pickard-Cambridge, 1875)
Thin-faced Spurred Sheetweaver Nearctic
Queens: Dalvay
Habitat: Mixed forest litter
Data source: CBG
- Centromerus sylvaticus* (Blackwall, 1841) Holarctic
Common Spurred Sheetweaver
Kings: Greenwich
Habitat: Mixed forest litter
Data source: CBG
- Ceraticelus bulbosus* (Emerton, 1882) Holarctic
Hump-eyed Armoured Money Spider
Queens: Bonshaw
Habitat: Mixed forest, grass, and litter
Data source: NPE
- Ceraticelus emertoni* (O. Pickard-Cambridge, 1874)
Emerton's Armoured Money Spider Nearctic
Kings: St. Catherines
Habitat: Crop fields, coastal grasslands
Data source: NPE
- Ceraticelus fissiceps* (O. Pickard-Cambridge, 1874)
Bicolored Armoured Money Spider Nearctic
Prince: Augustine Cove, Central Kildare; **Queens:** Bonshaw, Charlottetown; **Kings:** Forest Hill, Kingsboro, Launching, Lorne Valley
Habitat: Mixed forest litter and low shrubs
Data source: NPE
- Ceraticelus similis* (Banks, 1892) Nearctic
Broad Armoured Money Spider
Queens: Cavendish, Dalvay
Habitat: Mixed forest litter and low shrubs
Data source: CBG

Ceratinella brunnea Emerton, 1882 Nearctic
Brown Waxed Money Spider

Queens: Bonshaw, Cavendish, Dalvay, Kellys Cross; **Kings:** Greenwich, New Zealand
Habitat: Mixed forest and adjacent grasslands, low shrubs
Data source: CBG, NPE

Ceratinopsis nigriceps Emerton, 1882 Nearctic
Stump-armed Arboreal Money Spider

Queens: Kellys Cross; **Kings:** Cardigan, Kingsboro, Launching, Summerville
Habitat: Mixed forest
Data source: NPE

Collinsia plumosa (Emerton, 1882) Nearctic
Feathered Money Spider

Queens: Dalvay; **Kings:** East Lake, Greenwich
Habitat: Mixed forest, low bushes and ground
Data source: CBG, NPE

Diplocephalus subrostratus (O. Pickard-Cambridge, 1873)
Common Muppet Money Spider Holarctic

Queens: Brackley Beach, Cavendish
Habitat: Mixed forest, meadows
Data source: CBG

**Diplostyla concolor* (Wider, 1834) Holarctic
Long-spined Sheetweaver

Queens: Brackley Beach, Cavendish, Orwell; **Kings:** Greenwich, Launching, Savage Harbour
Habitat: Mixed forest, low shrubs and bushes, beaches, gardens, cultivated lands
Data source: CBG, NPE

Drapetisca alteranda Chamberlin, 1909 Nearctic
Northern Long-toothed Sheetweaver

Queens: Bonshaw, Dalvay
Habitat: Mixed forest
Data source: CBG, NPE

Erigone alettris Crosby & Bishop, 1928 Holarctic
Common Money Spider

Prince: North Tryon; **Queens:** Cavendish, Charlottetown; **Kings:** Greenwich, Kingsboro
Habitat: Mixed forest, bogs, litter, stones and low herbs near beaches
Data source: CBG, NPE

Erigone arctica (White, 1852) Holarctic
Circumpolar Money Spider

Prince: Miscouche
Habitat: Moist open habitats e.g., heathlands
Data source: CBG

**Erigone autumnalis* Emerton, 1882 Holarctic
Autumn Money Spider
Locality unavailable
Habitat: Fields
Data source: Unavailable

Erigone blaesa Crosby & Bishop, 1928 Nearctic
Faltering Money Spider

Queens: Cavendish; **Kings:** Cherry Island
Habitat: Litter near fresh and saltwater beaches/shores, sand dunes
Data source: NPE

**Erigone dentipalpis* (Wider, 1834) Palearctic
Toothed-palped Money Spider (introduced)

Kings: Head of Cardigan, Summerville
Habitat: Coastal barrens, mixed forest, gardens
Data source: NPE

**Grammonota angusta* Dondale, 1959 Nearctic
Slender Patterned Money Spider

Prince: Augustine Cove, Miscouche, Norway; **Queens:** Bonshaw, Cavendish, Charlottetown, Dalvay, Kellys Cross; **Kings:** Kingsboro, Launching, New Perth, Summerville, Thomas Island
Habitat: Mixed forest, low vegetation, gardens
Data source: CBG, NPE

Grammonota gentilis Banks, 1898 Nearctic
Kinsman Patterned Money Spider

Prince: Miscouche; **Queens:** Cavendish, Dalvay; **Kings:** Summerville
Habitat: Mixed forest
Data source: CBG, NPE

**Grammonota maritima* Emerton, 1925 Nearctic
Maritime Patterned Money Spider

Locality unavailable
Habitat: Coastal barrens
Data source: Unavailable/specimen record unverifiable

Grammonota pictilis (O. Pickard-Cambridge, 1875)
Painted Patterned Money Spider Nearctic

Queens: Brackley Beach, Cavendish, Dalvay
Habitat: Coniferous foliage
Data source: CBG

Grammonota vittata Barrows, 1919 Nearctic
Banded Patterned Money Spider

Queens: Glenfinnan
Habitat: Low vegetation, especially near bogs
Data source: NPE

Hypomma marxi (Keyserling, 1886) Nearctic
Marx's Under-eyed Money Spider

Poeciloneura calcaratus (Emerton, 1909) Nearctic
Spurred Variegated Sheetweaver

Prince: Augustine Cove; **Queens:** Bonshaw, Dalvay; **Kings:** Launching
Habitat: Mixed coniferous forest litter, beach and shrub litter
Data source: CBG, NPE

Porrhomma terrestre (Emerton, 1882) Nearctic
 Terrestrial Wide-eyed Sheetweaver
Queens: Covehead
Habitat: Mixed coniferous forest
Data source: CBG

Sciastes truncatus (Emerton, 1882) Nearctic
 Short-armed Money Spider
Queens: Dalvay
Habitat: Mixed coniferous forest, understory, and litter
Data source: CBG

Scylaceus pallidus (Emerton, 1882) Nearctic
 Blemish Money Spider
Queens: Dalvay
Habitat: Mixed coniferous forest, especially on ground in mosses
Data source: CBG

Soulgas corticarius (Emerton, 1909) Nearctic
 Coathook Money Spider
Prince: Central Kildare; **Queens:** Covehead, Dalvay
Habitat: Mixed coniferous forest litter and coastal areas
Data source: CBG, NPE

Wabasso quaestio (Chamberlin, 1949) Nearctic
 Short-tongued Money Spider
Kings: Kingsboro
Habitat: Mixed coniferous forest, moist open areas, coastal barrens
Data source: NPE

Walckenaeria communis (Emerton, 1882) Nearctic
 Common Erudite Money Spider
Queens: Dalvay; **Kings:** Corraville, Launching
Habitat: In moss and moist litter in mixed coniferous forest, bogs, pond and lake shores
Data source: CBG, NPE

Walckenaeria exigua Millidge, 1983 Nearctic
 Small Horned Erudite Money Spider
Queens: Dalvay
Habitat: In moss and moist litter in mixed coniferous forest, bogs, shrub areas
Data source: CBG

Walckenaeria lepida (Kulczyński, 1885) Holarctic
 Pleasant Erudite Money Spider

Queens: Charlottetown, Dalvay, Kellys Cross;
Kings: Launching
Habitat: Mixed forest or shrub litter
Data source: CBG, NPE

Walckenaeria pinocchio (Kaston, 1945) Nearctic
 Pinocchio Erudite Money Spider
Queens: Dalvay
Habitat: Mixed coniferous forest
Data source: CBG

LIOCRANIDAE (1 species)
Agroeca ornata Banks, 1892 Nearctic
 Ornated Spiny-legged Spider
Prince: Central Kildare; **Queens:** Dalvay;
Kings: Greenwich, Launching
Habitat: Ground litter or decaying logs in mixed forests, and on the ground in pastures, meadows, marshes, sphagnum bogs, mosses, and lichens
Data source: CBG, NPE

LYCOSIDAE (12 species)
Alopecosa aculeata Charitonov 1931 Holarctic
 Pointed Wolf Spider
Prince: North Tryon; **Queens:** Marshfield
Habitat: Sunlit forest glades and shrubby meadows
Data source: NPE

**Arctosa littoralis* (Hentz, 1844) Nearctic
 Shoreline Wolf Spider
Kings: Greenwich, Launching
Habitat: Sandy beaches of both fresh- and salt-water
Data source: Dondale and Redner 1990, NPE

Gladicosa gulosa (Walckenaer, 1837) Nearctic
 Drumming Sword Wolf Spider
Kings: Summerville
Habitat: Open deciduous forest
Data source: NPE

Pardosa fuscula (Thorell, 1875) Nearctic
 Brown Thin-legged Wolf Spider
Kings: Abney, Corraville
Habitat: Moist habitats, mainly fresh and salt marshes, bogs, and meadows, occasionally coniferous forest
Data source: NPE

**Pardosa moesta* Banks, 1892 Nearctic
 Shiny Thin-legged Wolf Spider
Queens: Covehead, Brackley Beach; **Kings:** Abney, Corraville, Launching, Greenwich
Habitat: Meadows, hayfields, marshes, bogs, open forest, and urban lawns
Data source: Dondale and Redner 1990, CBG, NPE

- *Pardosa saxatilis* (Hentz, 1844) Nearctic
Saxatile Thin-legged Wolf Spider
Collection locality not listed in source
Habitat: Grassy fields and meadows, but also found in marshes, bogs, deciduous woods, and sandy beaches
Data source: Dondale and Redner 1990
- Pardosa xerampelina* (Keyserling, 1877) Nearctic
Ubiquitous Thin-legged Wolf Spider
Prince: Central Kildare
Habitat: Short grass, among herbs along streams, in dry stony river beds and lakeshores, in cultivated fields, along roadsides, in open forests
Data source: NPE
- *Pirata piraticus* (Clerck, 1757) Holarctic
Common Pirate Wolf Spider
Collection locality not listed in source
Habitat: Marshes (fresh and salt), swamps, bogs, and shores of lakes and streams
Data source: Dondale and Redner 1990
- Piratula cantralli* (Wallace & Exline, 1978) Nearctic
Cantrall's Pirate Wolf Spider
Queens: Glenfinnan, Dalvay; **Kings**: Corraville
Habitat: Marshes
Data source: CBG, NPE
- Piratula minuta* (Emerton, 1885) Nearctic
Small Pirate Wolf Spider
Queens: Dalvay
Habitat: Meadows, hayfields, marshes, swamps, and bogs
Data source: CBG
- Trochosa ruricola* (De Geer, 1778) Holarctic
Eurasian Litter Wolf Spider (introduced)
Queens: Cavendish, Covehead, Dalvay, Harrington; **Kings**: Savage Harbour, Summerville
Habitat: Forest, scrub, grasslands, lawns
Data source: CBG, NPE
- *Trochosa terricola* Thorell, 1856 Holarctic
Common Litter Wolf Spider
Prince: Cap Egmont; **Queens**: Harrington, Dalvay, Charlottetown
Habitat: Forest, grasslands, heathlands, under stones and logs
Data source: Dondale and Redner 1990, CBG, NPE
- PHILODROMIDAE (11 species)
**Philodromus cespitum* (Walckenaer, 1802) Holarctic
Common Running Crab Spider
Queens: Covehead, Dalvay, Donagh
Habitat: On grasses, shrubs, and trees
Data source: Dondale and Redner 1978, CBG, NPE
- Philodromus histrio* (Latreille, 1819) Holarctic
Attractive Running Crab Spider
Kings: Greenwich
Habitat: On sagebrush in the west and on heath plants, weeds, and tall grasses
Data source: CBG
- Philodromus oneida* Levi, 1951 Nearctic
Oneida Running Crab Spider
Queens: Dalvay
Habitat: Foliage of various trees
Data source: CBG
- Philodromus peninsulanus* Gertsch, 1934 Nearctic
Peninsular Running Crab Spider
Queens: Dalvay
Habitat: Openings in mixed coniferous forest
Data source: CBG
- *Philodromus placidus* Banks, 1892 Nearctic
Conifer Running Crab Spider
Kings: Launching
Habitat: Foliage of conifers
Data source: Dondale and Redner 1978, NPE
- Philodromus praelustris* Keyserling, 1880 Nearctic
Resplendant Running Crab Spider
Queens: Brackley Beach, Dalvay; **Kings**: Head of Cardigan
Habitat: Tree trunks and branches, and on wooden fences and buildings
Data source: CBG, NPE
- Philodromus rufus* Dondale, 1964 Nearctic
White-striped Running Crab Spider
Prince: Augustine Cove, Central Kildare, Norway; **Queens**: Brackley Beach, Cavendish, Covehead, Dalvay, Marshfield; **Kings**: Cardigan, Launching, New Perth, Summerville
Habitat: Foliage of coniferous and deciduous trees and shrubs
Data source: CBG, NPE
- Thanatus formicinus* (Clerck, 1757) Holarctic
Ant Running Crab Spider
Kings: West St. Peters
Habitat: Mixed coniferous forest, under stones, and in grasses and low shrubs in meadows or orchards
Data source: NPE
- Thanatus striatus* C.L. Koch, 1845 Holarctic
Hairy Running Crab Spider
Queens: Brackley Beach
Habitat: Grassland litter and low vegetation
Data source: CBG

Tibellus maritimus (Menge, 1875) Holarctic
Grooved Running Crab Spider

Queens: Brackley Point; **Kings:** Greenwich

Habitat: Tall grass

Data source: CBG

Tibellus oblongus (Walckenaer, 1802) Holarctic
Slender Running Crab Spider

Prince: North Cape; **Queens:** Blooming Point, Grandview, South Melville; **Kings:** Head of Cardigan, Summerville

Habitat: Tall grass

Data source: NPE

PHOLCIDAE (1 species)

Pholcus phalangioides (Fuesslin, 1775) Palearctic
Long-bodied Cellar Spider (introduced)

Prince: North Tryon; **Queens:** Donagh; **Kings:** Brudenell, Head of Cardigan, Summerville

Habitat: In houses and other buildings

Data source: NPE

PHRUROLITHIDAE (2 species)

Phrurotimpus borealis (Emerton, 1911) Nearctic
Greater Antmimic Corinne Spider

Queens: Brackley Beach, Cavendish; **Kings:** Greenwich

Habitat: Leaf litter of coniferous or deciduous forest, prairies, bogs, swamps, and meadows, on rocky hill-sides, and under stones and beach debris

Data source: CBG

Scotinella minnetonka (Chamberlin & Gertsch, 1930)
Midwestern Antmimic Corinne Spider Nearctic

Kings: Greenwich

Habitat: On ground in pastures, meadows, swamps, deciduous forests, under stones

Data source: CBG

PISAUROIDAE (1 species)

**Dolomedes triton* (Walckenaer, 1837) Nearctic
Six-spotted Fishing Spider

Queens: Dalvay; **Prince:** Huntley, Gordon's Pond, MacNeill's Mills; **Queens:** Brackley Beach, Cavendish; **Kings:** Head of Cardigan, Forest Hill

Habitat: At the margins of ponds, lakes, and the quiet parts of rivers and streams

Data source: Knysh and Giberson 2012, CBG, NPE

SALTICIDAE (10 species)

Eris militaris (Hentz, 1845) Nearctic
Bronze Jumping Spider

Prince: Central Kildare, Portage, St. Nicholas, Norway, Coleman; **Queens:** Avondale, Cavendish, Bon-

shaw, Blooming Point, Dalvay, Charlottetown, Covehead, Marshfield; **Kings:** Abney, Brudenell, Greenwich, Head of Cardigan, Forest Hill, Launching, Milltown Cross, Savage Harbour, Summerville, West St. Peters

Habitat: On foliage of grasses, herbs, orchards, deciduous trees, shrubs

Data source: CBG, NPE

Evarcha hoyi (Peckham & Peckham, 1883) Nearctic
Hoy's Knobbed Jumping Spider

Kings: Launching, Forest Hill

Habitat: Shrubs, herbs, grasses, and other low vegetation

Data source: NPE

Neon nelli Peckham & Peckham, 1888 Nearctic
Nell's Tiny Jumping Spider

Queens: Cavendish, Brackley Beach, Dalvay

Habitat: Mixed hardwood leaf litter

Data source: CBG

**Pelegrina flavipes* (Peckham & Peckham, 1888)
Big-headed White-cheeked Jumping Spider Nearctic

Prince: Norway; **Queens:** Bonshaw, Charlottetown, Donagh; **Kings:** Forest Hill, Kingsboro, Launching, Savage Harbour, Summerville, Thomas Island, Woodville Mills

Habitat: Mixed coniferous foliage and bark, tall grasses in marshlands and fields

Data source: NPE

Pelegrina proterva (Walckenaer, 1837) Nearctic
Common White-cheeked Jumping Spider

Prince: Central Kildare, Norway; **Queens:** Cavendish, Bonshaw, Brackley Beach, Dalvay, Donagh, Kelly's Cross, Marshfield; **Kings:** Cape Bear, Forest Hill, Lorne Valley, Launching, Savage Harbour, Summerville

Habitat: Woodland understorey

Data source: CBG, NPE

Phidippus princeps (Peckham & Peckham, 1883)
Sinuous Tufted Jumping Spider Nearctic

Kings: Summerville

Habitat: Old fields, goldenrod

Data source: NPE, previous record unverifiable (immature *Phidippus* specimen)

Salticus scenicus (Clerck, 1757) Palearctic
Zebra Jumping Spider (introduced)

Prince: North Tryon; **Queens:** Brackley Beach, Donagh, Winsloe; **Kings:** Summerville

Habitat: On and in houses and other buildings, on fences, meadows, and fields

Data source: CBG, NPE

**Sittiflor floricola palustris* (Peckham & Peckham, 1883)

Flower Patterned Jumping Spider Nearctic

Prince: West Point, Central Kildare; **Queens:** Covehead, Mount Albion, Wheatley River

Habitat: Bogs, marshes, fens, and meadows

Data source: CBG, NPE

Synageles venator (Lucas, 1836) Palaeartic
Palaeartic Antmimic Jumping Spider (introduced)

Queens: Charlottetown

Habitat: Sand dunes on the coast, tussocky or scrub vegetation close to wet areas

Data source: NPE

**Tutelina similis* (Banks, 1895) Nearctic
Thick-spined Jumping Spider

Kings: Launching

Habitat: Grasslands, meadows, and other areas of low vegetation

Data source: NPE

TETRAGNATHIDAE (10 species)

**Pachygnatha brevis* Keyserling, 1884 Nearctic
Northeastern Thick Long-jawed Spider

Queens: Bonshaw, Marshfield; **Kings:** Forest Hill, Lorne Valley

Habitat: Swamps and salt marshes or plant debris near water

Data source: Dondale et al. 2003, NPE

**Tetragnatha caudata* Emerton, 1884 Nearctic
Tailed Long-jawed Spider

Prince: Portage

Habitat: Bogs, marshes, and swamps among reeds and tall grasses

Data source: Dondale et al. 2003, NPE

**Tetragnatha dearmata* Thorell, 1873 Holarctic
Uncommon Long-jawed Spider

Queens: Dalvay

Habitat: On trees and understorey shrubs in mixed coniferous forests, and swamp grasses

Data source: Dondale et al. 2003, CBG

Tetragnatha elongata Walckenaer, 1841 Nearctic
Elongated Long-jawed Spider

Queens: Blooming Point, Culloden, Dalvay, Glenfinnan Avondale, South Melville; **Kings:** Launching

Habitat: On branches that overhang streams, especially near forest

Data source: CBG, NPE

**Tetragnatha extensa* (L., 1758) Holarctic
Northern Long-jawed Spider

Queens: Covehead; **Kings:** Head of Cardigan, Milltown Cross, St. Peters Harbour, Summerville

Habitat: Widespread on shrubs and trees in meadows

Data source: Dondale et al. 2003, CBG, NPE

Tetragnatha guatemalensis O. Pickard-Cambridge, 1889

Guatemala Long-jawed Spider Nearctic

Queens: Covehead, Dalvay

Habitat: Streamside or lakeside shrubs and tall herbs

Data source: CBG

**Tetragnatha laboriosa* Hentz, 1850 Nearctic
Silver Long-jawed Spider

Prince: Kelvin, Miscouche, North Tryon; **Queens:** Blooming Point, Cavendish, Covehead, Glenfinnan; **Kings:** Corraville, Greenwich, St. Peters Harbour, Summerville

Habitat: Fields, roadsides, and crops, near or away from water, but also bogs, meadows, and marshes

Data source: Dondale et al. 2003, CBG, NPE

Tetragnatha shoshone Levi, 1981 Holarctic
Shoshone Long-jawed Spider

Queens: Cavendish, Dalvay; **Kings:** Greenwich

Habitat: Tall plants near lakes

Data source: CBG

Tetragnatha versicolor Walckenaer, 1841 Nearctic
Common Long-jawed Spider

Queens: Cavendish, Dalvay

Habitat: Trees and shrubs near water, but also mixed conifer forest

Data source: CBG

Tetragnatha viridis Walckenaer, 1841 Nearctic
Green Long-jawed Spider

Queens: Dalvay; **Kings:** Greenwich, St. Peters Harbour

Habitat: On coniferous trees, namely pine and balsam fir

Data source: CBG, NPE

THERIDIIDAE (27 species)

**Canalidion montanum* (Emerton, 1882) Holarctic
Montane Cobweaver

Queens: Dalvay

Habitat: Shrubs and trees in mixed coniferous forest

Data source: CBG

Crustulina sticta (O. Pickard-Cambridge, 1861)
Common Dimpled Widow Spider Holarctic

Queens: Covehead

Habitat: Among stones and among herbs and litter near beaches

Data source: CBG

- Dipoenia nigra* (Emerton, 1882) Nearctic
Common Highbrowed Cobweaver
Kings: Corraville
Habitat: Mixed forest and shrubs
Data source: NPE
- Enoplognatha latimana* Hippa & Oksala, 1982
Cavernous Long-jawed Cobweaver Palearctic
(introduced)
Prince: West Point; **Queens:** Donagh, Grandview;
Kings: St. Peters Harbour, Summerville
Habitat: Fields and field margins; open, dry habitats,
low vegetation, and shrubs
Data source: NPE
- **Enoplognatha ovata* (Clerck, 1757) Palearctic
Polymorphic Long-jawed Cobweaver (introduced)
Prince: Central Kildare; **Queens:** Blooming Point,
Cavendish, Charlottetown, Dalvay, Donagh, South
Melville; **Kings:** Little Sands, Summerville
Habitat: Fields and field margins, open habitats, low
vegetation and shrubs, gardens
Data source: CBG, NPE
- Euryopsis argentea* Emerton, 1882 Holarctic
Black-headed Triangular Cobweaver
Queens: Covehead
Habitat: Mixed forest litter
Data source: CBG
- Euryopsis funebris* (Hentz, 1850) Nearctic
Eastern Triangular Cobweaver
Queens: Covehead
Habitat: Mixed forest litter
Data source: CBG
- Neospintharus trigonum* (Hentz, 1850) Nearctic
Horned Parasitic Cobweaver
Queens: Cavendish, Dalvay
Habitat: Mixed forest
Data source: CBG
- Neottiura bimaculata* (L., 1767) Palearctic
Bimaculated Cobweaver (introduced)
Queens: Covehead; **Kings:** Greenwich
Habitat: Low vegetation and bushes, sometimes low
branches of trees, broad habitats
Data source: CBG
- Parasteatoda tabulata* (Levi, 1980) Palearctic
Wandering House Cobweaver (introduced)
Prince: Central Kildare, North Tryon; **Queens:**
Charlottetown, Donagh; **Kings:** Brudenell, Elliot-
vale, Savage Harbour, Summerville,
West St. Peters
- Habitat:* In houses, sheds, other buildings, some-
times gardens
Data source: NPE
- Parasteatoda tepidariorum* (C. L. Koch, 1841)
Common House Cobweaver South America
(introduced)
Queens: Charlottetown
Habitat: In houses, sheds, other buildings, some-
times gardens
Data source: NPE
- Phoroncidia americana* (Emerton, 1882) Nearctic
Hump-backed Cobweaver
Kings: Launching
Habitat: Coniferous tree foliage (e.g., cedar, pine)
near farms and adjacent fields, sometimes litter
Data source: NPE
- Platnickina tincta* (Walckenaer, 1802) Palearctic
Conifer Cobweaver (introduced)
Queens: Cavendish, Marshfield; **Kings:** Savage
Harbour
Habitat: Shrubs and tree foliage, gardens, parks,
roadsides
Data source: CBG, NPE
- Robertus riparius* (Keyserling, 1886) Nearctic
Bent Immaculate Cobweaver
Kings: Launching, New Zealand
Habitat: Mixed coniferous forest litter
Data source: NPE
- Rugathodes sexpunctatus* (Emerton, 1882) Holarctic
Six-spotted Cobweaver
Queens: Cavendish
Habitat: Mixed coniferous forest, shrubs, gardens,
parks
Data source: CBG
- **Steatoda albomaculata* (De Geer, 1778) Holarctic
Punctate False Black Widow Spider
Locality unavailable
Habitat: Sandy areas, sparsely vegetated areas,
rocky ground
Data source: Unavailable/specimen record unverifi-
able
- Steatoda bipunctata* (L., 1758) Palearctic
Eurasian False Black Widow Spider (introduced)
Prince: Traveller's Rest, North Tryon, Central Kil-
dare; **Queens:** Charlottetown, Marshfield;
Kings: Head of Cardigan, Summerville
Habitat: Near human-made structures, e.g., fences,
buildings, houses, sheds
Data source: NPE

Theridion differens Emerton, 1882 Nearctic
Common Long-legged Cobweaver

Prince: Central Kildare; **Queens:** Brackley Beach, Covehead, Marshfield
Habitat: Low vegetation in mixed coniferous forest, wetland areas
Data source: CBG, NPE

Theridion frondeum Hentz, 1850 Nearctic
Eastern Long-legged Cobweaver

Prince: Portage; **Queens:** Blooming Point, Dalvay, South Melville, Wood Islands; **Kings:** Summerville
Habitat: Deciduous forest, shrubs and herbs
Data source: CBG, NPE

**Theridion glaucescens* Becker, 1879 Nearctic
Large-spined Long-legged Cobweaver

Queens: Dalvay
Habitat: Mixed coniferous forest, low foliage
Data source: CBG

Theridion murarium Emerton, 1882 Nearctic
Fence Long-legged Cobweaver

Prince: Central Kildare; **Queens:** Dalvay; **Kings:** New Perth
Habitat: Mixed coniferous forest
Data source: CBG, NPE

Theridion pictum (Walckenaer, 1802) Holarctic
Wetland Long-legged Cobweaver

Queens: Charlottetown, Dalvay
Habitat: Mixed coniferous forest
Data source: CBG, NPE

Theridion varians Hahn, 1833 Palearctic
Eurasian Long-legged Cobweaver (introduced)

Prince: North Tryon; **Queens:** Cavendish; **Kings:** Summerville
Habitat: Tree and shrub foliage, fences, grasslands
Data source: CBG, NPE

Theridula emertoni Levi, 1954 Nearctic
Emerton's Bitubercled Cobweaver

Queens: Blooming Point
Habitat: Mixed coniferous forest
Data source: NPE

Thymoites unimaculatus (Emerton, 1882) Nearctic
Spotted Cobweaver

Queens: Covehead; **Kings:** Canavoy
Habitat: Fields, mixed coniferous forest, marshes
Data source: CBG, NPE

Wamba crispulus (Simon, 1895) Nearctic
Bayonet Cobweaver

Prince: Central Kildare; **Queens:** Dalvay
Habitat: Mixed coniferous forest, grasslands
Data source: CBG, NPE

Yunohamella lyrica (Walckenaer, 1841) Holarctic
Lyric Cobweaver

Queens: Dalvay; **Kings:** Launching
Habitat: Most common in dry, pine-dominated areas, but also in other coniferous trees and grasslands
Data source: CBG, NPE

THERIDIOSOMATIDAE (1 species)
Theridiosoma gemmosum (L. Koch, 1877) Holarctic
Common Eastern Ray Spider

Queens: Dalvay; **Kings:** Greenwich
Habitat: Damp areas (e.g., swamps), or wet cliff faces and overhanging stream banks, grassy fields with rose bushes, mossy ground in white spruce stand
Data source: CBG

THOMISIDAE (8 species)
Bassaniana utahensis (Gertsch, 1932) Nearctic
Utah Bark Crab Spider

Prince: Central Kildare; **Queens:** Brackley Beach
Habitat: Under tree bark and in litter of mixed forest
Data source: CBG, NPE

**Misumena vatia* (Clerck, 1757) Holarctic
Goldenrod Crab Spider

Prince: North Cape, St. Nicholas; **Queens:** Cavendish, Covehead, Dalvay, Donagh; **Kings:** Greenwich, Head of Cardigan, Launching, Summerville, West St. Peters
Habitat: On flowers and foliage of many herbs, shrubs, and deciduous trees in pastures, meadows, and orchards
Data source: CBG, NPE

**Ozyptila distans* Dondale & Redner, 1975 Nearctic
Distant Leaf litter Crab Spider

Queens: Brackley Beach, Dalvay, Kellys Cross; **Kings:** Greenwich, Head of Cardigan
Habitat: Swamps, sphagnum bogs, abandoned fields, and pine litter
Data source: Dondale and Redner 1978, CBG, NPE

Tmarus angulatus (Walckenaer, 1837) Nearctic
Tuberculated Crab Spider

Kings: Head of Cardigan, Summerville
Habitat: Mixed forest and nearby grasslands and shrub vegetation
Data source: NPE

Xysticus canadensis Gertsch, 1934 Holarctic
Boreal Ground Crab Spider

Queens: Dalvay
Habitat: Mixed coniferous forest
Data source: CBG

Xysticus emertoni Keyserling, 1880 Holarctic
Emerton's Ground Crab Spider

Kings: Corraville, Summerville

Habitat: Fields, meadows, bogs, and herbaceous vegetation

Data source: NPE

Xysticus punctatus Keyserling, 1880 Nearctic
Punctated Ground Crab Spider

Queens: Dalvay; **Kings:** Savage Harbour

Habitat: On trees and litter of mixed coniferous forest

Data source: CBG, NPE

Xysticus triguttatus Keyserling, 1880 Nearctic
Three-banded Ground Crab Spider

Prince: Central Kildare

Habitat: On ground in grasslands, on shrubs and herbs

Data source: NPE

ULOBORIDAE (1 species)

Hyptiotes gertschi Chamberlin & Ivie, 1935 Nearctic
Gertsch's Triangle Weaver

Kings: Launching

Habitat: Mixed coniferous forest, pine stands on trees

Data source: NPE

Discussion

We have shown that collaboration among experts and volunteer citizen scientists can contribute effectively to our understanding of the diversity and distribution of species. Broad-scale contributions from the public overcame the logistic difficulties associated with collecting specimens from a diverse range of habitats and geographic locations across PEI. The naturalists engaged, organized, and trained citizens in collection and preservation techniques and the experts identified, recorded, and prepared voucher specimens. This approach is particularly important in efforts to document the current state of biodiversity, including the conservation status of species across the globe.

We have increased the number of spider species known to occur on PEI to 198 through the combined efforts of professional researchers using DNA barcoding technology and comparative morphology and through the help of citizen scientists using traditional collecting and identification methods. Concerted volunteer effort in combination with novel technology, such as DNA barcoding, have produced a baseline record of spider diversity for the province.

The CBG and Nature PEI studies complemented each other in unforeseen ways. Although the CBG surveyed one protected area intensively, citizen scientists surveyed a range of habitat types over a wide geographic area, demonstrating that many of the species collected within the 27-km² national park are distributed across the entire province. The increased number of specimens collected via a citizen science approach can

result in an increased opportunity for studies of species occurrence, relative abundance, and relationships (Acorn 2017). In addition, an especially noteworthy positive outcome is that more active community engagement in conservation was encouraged and the project was widely reported through various media (e.g., CBC News 2016), providing positive feedback for involvement in community collection efforts.

Collaboration among experts and citizen scientists in this time of rapid species loss is imperative to help document the diversity and distribution of species on earth (Ceballos *et al.* 2015). It does take effort by professionals and naturalists to engage and train the public in such ventures, but fortunately, there are ever-growing opportunities for academics and governmental and non-governmental agencies to engage the public and inform them about how they can contribute to these efforts (Bonney *et al.* 2009, 2014; Prudic *et al.* 2017).

The citizen science approach also presents some challenges; for example, participants tend to sample sites familiar to them and the quality of specimens and associated data submitted can be highly variable. Thus, less than 20% of the over 4300 specimens collected by the Nature PEI citizen scientists were adults that could be positively identified by morphological characteristics. Nonetheless, their efforts yielded about a quarter of the total number of species, with many others overlapping the parallel DNA barcoding. Efforts to conduct faunistic surveys such as these even in a province of this size would be more challenging without contributions from the public.

PEI lies in the Gulf of Saint Lawrence with New Brunswick to its west and south, and Nova Scotia to its east and south. Thus, unsurprisingly and similar to other species groups, the PEI spider fauna largely represents a subset of species found in those adjacent provinces (e.g., Adler *et al.* 2005; Majka *et al.* 2008). Many were likely able to colonize PEI when it was connected to the mainland some 10 000 years ago (Shaw *et al.* 2002). However, the proximity of the adjacent mainland means that many spider species are capable of colonizing the island via aerial ballooning (Greenstone 1990) or even via natural rafts, such as floating algae (Coffin *et al.* 2017). Humans have likely introduced others accidentally. Despite PEI's relatively small human population, it is densely populated and is a popular tourist destination during summer months.

Some species previously reported from PEI were not collected during the Nature PEI or CBG studies. This absence could indicate that these species are rare on PEI, are present in habitats that were not well surveyed in the two studies (e.g., *Pirata piraticus* in wetlands), were originally misidentified, or simply no longer exist on the island. Although PEI is the smallest province in Canada, it possesses a diversity of habitat types. As with other animal groups, some spider species are habitat generalists, while others are specialists depending on their physiological requirements. In some

cases, narrow physiological requirements dictate that species distributions may change dramatically across very small spatial scales (e.g., microhabitats; DeVito *et al.* 2004). For example, DeVito *et al.* (2004) found that three species of wolf spider distributed themselves in proximity to a river corresponding to their desiccation thresholds. A high turnover in species across the landscape may mean that some are missed in faunistic studies. Despite intensive sampling by the CBG, it was spatially restricted and focussed on the national park, whereas the efforts by Nature PEI were broad in geographic scope, but much less intensive and often consisted of a single collection at a given site.

As is typical for many groups in eastern North America, several introduced species are now well established on PEI. The degree to which introduced species may affect native species is not well known, but some evidence supports the idea that such introductions could lead to competitive exclusion (Houser *et al.* 2014).

Some species collected in this project (e.g., *Gladicosa gulosa*) are otherwise known only from more southern localities (e.g., southern Nova Scotia, Quebec, or Ontario) in Canada or in the continental United States (Dondale and Redner 1990). PEI lies near the boreal-temperate transition zone and the discovery of such species could indicate a northward shift in their range. Because we do not have reliable information about the past presence of species on the island, it is impossible to know for certain how long this species or others have existed there. This is in contrast to species such as *Misumena vatia* or *Pardosa xerampelina*, which have been collected in all other provinces in Canada and some territories, as well as the Magdalen Islands, in the case of the latter, but never before documented from PEI (Dondale and Redner 1978, 1990).

The finding that the Linyphiidae was the most speciose group in this collection is typical of other spider lists in Canada (e.g., Dondale *et al.* 1997; Pickavance and Dondale 2005), including those from community ecology studies (e.g., Buddle 2001). Indeed, the Linyphiidae is the second most speciose family globally (second to the Salticidae), boasting over 4500 species (World Spider Catalog 2017), but their diversity is especially high in northern environments (e.g., Bowden and Buddle 2010).

Although we have made substantial progress in documenting the spiders of PEI, we expect that many additions remain to be made. Moreover, additional species could be found through further collection in areas that were not well sampled during this effort, such as sand dunes, hardwood stands, and various agricultural fields, marshes, and upper tree canopies, which could yield some unique species (Larivée and Buddle 2009). Collection in these areas could also benefit from more intensive pitfall trapping.

We achieved strategic collaboration among professional, naturalists, and citizen scientists, and emphasize that these relationships are mutually beneficial where

professionals are aided by the collection of data and citizens can learn more about local species and their natural history. We hope that our efforts inspire others to participate in such collaborative projects and to continue to contribute to social networks and online repositories dedicated to documenting species (e.g., iNaturalist). Still, professionally led research projects on biodiversity in PEI would likely yield further records and provide a better portrait of species community structure.

Author Contributions

R.C. indicated the need for a study and initiated discussion. J.J.B., K.M.K., G.A.B., R.B., and R.C. conceptualized the study and methods, J.J.B., G.A.B., and R.B. produced or compiled data. R.C. procured funding for the NPE portion of the project. K.M.K., R.C., C.F.H., and R.W.H. contributed to project administration by supervising and leading the NPE citizen science specimen collection initiative. M.A.A. created the map figure. J.J.B. and R.B. wrote the original draft of the article and undertook revisions. All authors contributed to revisions and approved the final manuscript.

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New records for Eastern Mosquito Fern (*Azolla cristata*, Salviniaceae) in Canada

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Abstract

We report a cluster of Eastern Mosquito Fern (*Azolla cristata*, Salviniaceae) populations in five watersheds within a 56-km² area of Leeds and Grenville County, Ontario. Some of the recently discovered populations were immense, one containing over two million individuals in 2016. These eastern Ontario populations are persistent, having been observed *in situ* continuously for four years. One population was confirmed after an apparent absence of at least 30 years and another was reported as present (or at least recurring) for approximately 50 years. We observed that Canadian *A. cristata* is capable, at least experimentally, of overwinter dormancy and subsequent renewal. *Azolla cristata* in eastern Ontario and western Quebec appears to represent naturally (if sporadically) occurring populations, likely transported from adjacent northern New York populations by migratory waterfowl. These natural occurrences are expected to be more frequent as climate change continues to reduce environmental barriers to the northward establishment of this and other southern taxa.

Key words: *Azolla cristata*; Eastern Mosquito Fern; climate change; native biodiversity; pteridophyte; Frontenac Axis; Ontario; Quebec

Introduction

The Salviniaceae is a small, cosmopolitan, mainly tropical family of aquatic, heterosporous, free-floating ferns (Svenson 1944; Lumpkin 1993). *Azolla*, the larger of the two genera in the family (traditionally seen as the distinct family, Azollaceae), is characterized by small, dichotomously branching, free-floating plants with lobed fronds (Figure 1) and short thread-like roots extending into the water (Cody and Britton 1989). *Azolla* is ephemeral (Evrard and Van Hove 2004), with populations experiencing brief periods of explosive growth followed by long periods of apparent absence or obscurity that can last for years, as found in this study. Populations frequently form mats several hectares in size that can extend more or less continuously for kilometres (Figure 2; Darbyshire 2002; Darbyshire and Thomson 2004).

All three species of *Azolla* occurring in Canada (Macoun 1890; Brunton 1986; Cody and Britton 1989) are rare here, and many populations have been considered to be non-native. The cosmopolitan Large Mosquito Fern (*Azolla filiculoides* J.-B. Lamarck) is native in parts of western North America and is probably introduced in southern British Columbia (BC; Douglas *et al.* 2000; F. Lomer pers. comm. 4 December 2017). A sterile *Azolla* specimen from Brantford, Ontario (ON; C. J. Rothfels and S. R. Spisani 795, 24 September 2003, HAM, D.F.B. personal herbarium) is believed to be *A. filiculoides* (based on the morphological distinctions described in Methods). It is reported elsewhere in the Great Lakes Region from the Niagara Frontier area of western

New York (NY; Eckel 2005, although not repeated in Weldy *et al.* 2018).

Occurrences of Mexican Mosquito Fern (*Azolla mexicana* Schlechtendal & Chamisso ex C. Presl), a widespread native species in western North America (Lumpkin 1993), are scattered through interior southern BC (Brunton 1986; Goward 1994). It is of conservation concern and assessed (COSEWIC 2008) and listed as threatened in Canada (SARA 2019). *Azolla mexicana* has also been discovered recently in coastal BC as an adventive beyond its natural range (Klinkenberg 2017).

Eastern Mosquito Fern (*Azolla cristata* G.-F. Kaulfuss (*A. caroliniana* auct., non C.L. Willdenow)); is found irregularly across much of the eastern United States and southward into South America (Svenson 1944; Wherry 1961; Lumpkin 1993; Crow and Hellquist 2000; Pereira *et al.* 2011). It is considered a secure species on a global scale (G5) but uncommon to rare in some northern portions of its North American range and critically imperilled (S1S2) in Canada in ON and BC (NatureServe 2019). The Canadian status of *A. cristata*, however, is ambiguous and it has not been assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Possible native populations have been reported in the western Lake Ontario area (both historical and contemporary at Hamilton and the Niagara Peninsula), near Ivy Lea (Leeds and Grenville County, hereafter, L & G County), and from York County (Pryer 1987; Eckel 2005; Oldham and Brinker 2009). Populations found along the Rideau and Ottawa Rivers in ON and Quebec (QU) were reported to represent non-native introductions (Darbyshire 2002; Darbyshire and Thom-

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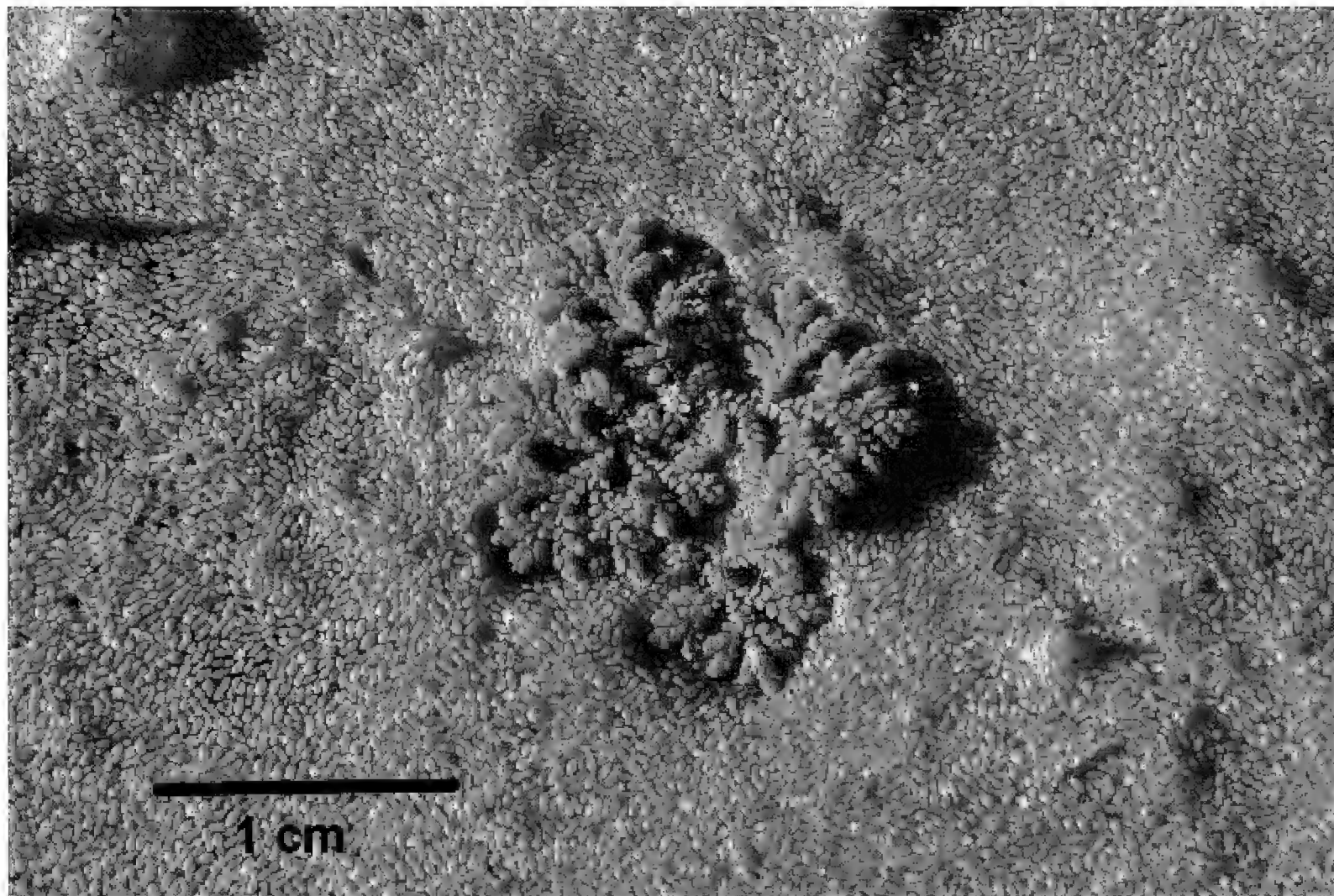


FIGURE 1. Single Eastern Mosquito Fern (*Azolla cristata*) plant in a watermeal (*Wolffia* spp.) mat at Maple Grove, Gananoque River, Leeds and Grenville County, Ontario. Photo: D.F. Brunton, 21 September 2016.

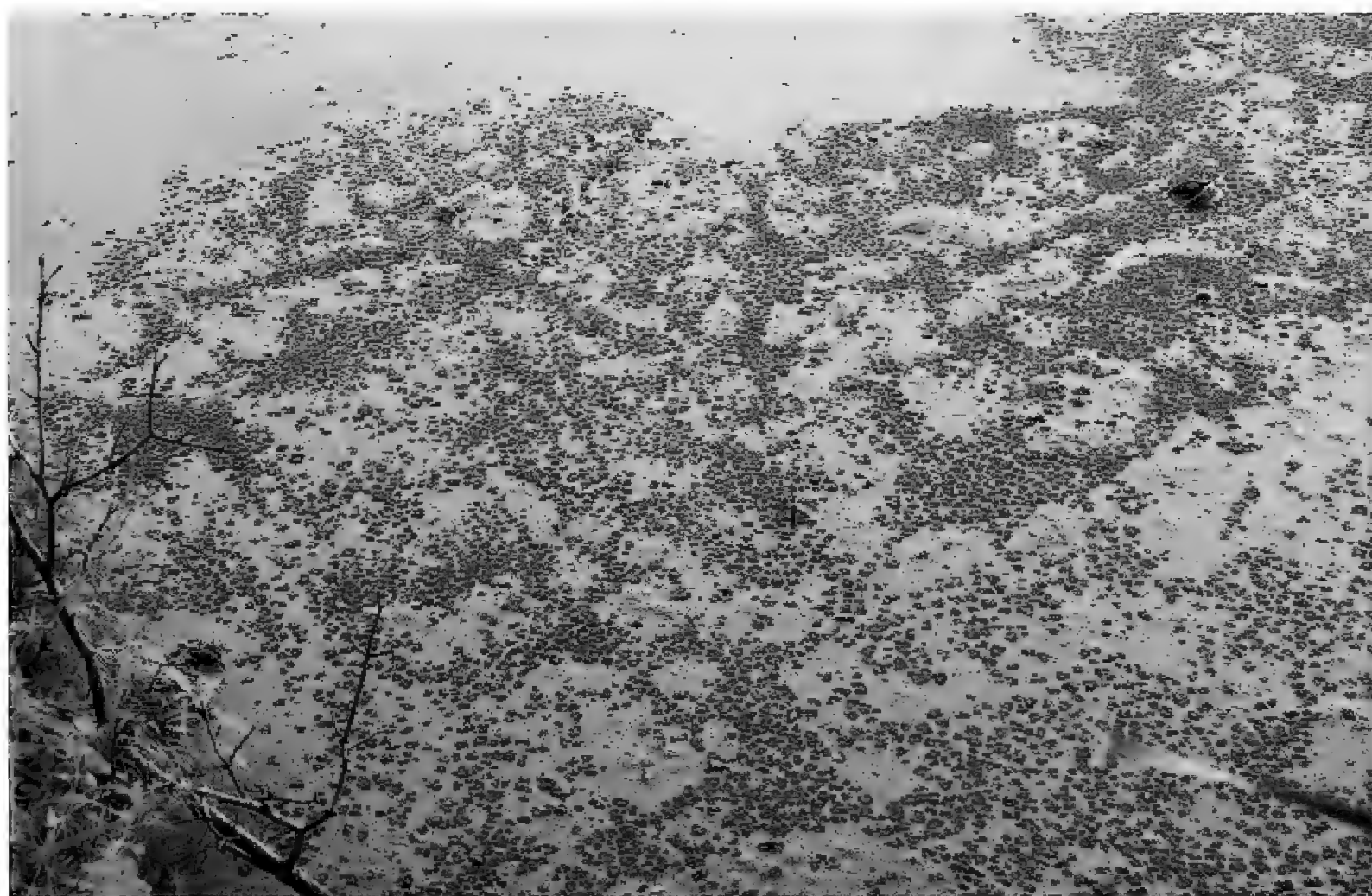


FIGURE 2. Large population of Eastern Mosquito Fern (*Azolla cristata*; darker plants) atop a floating mat of watermeal (*Wolffia* spp.), Star Duckweed (*Lemna trisulca*), and Great Duckweed (*Spirodella polyrhiza*) at Kinsman Park, Gananoque, Leeds and Grenville County, Ontario. Photo: D.F. Brunton, 27 September 2016.

son 2004). Recent occurrences in urban areas in southern BC are reported as being introduced (Douglas *et al.* 2000; Klinkenberg 2017). Eastern Canadian *A. cristata* populations have been considered incapable of persisting in the wild for more than one or two seasons (Darbyshire 2002), presumably constrained by Canadian winter conditions. It has been suggested that introduced Canadian populations likely resulted from the dumping of the contents of home aquaria into local waterways (Darbyshire 2002; Darbyshire and Thomson 2004; Klinkenberg 2017).

The discovery and rediscovery of vast and long-persisting populations of *A. cristata* in eastern ON are reported here and the implications of those discoveries are reviewed.

Methods

Following the September 2014 opportunistic discovery of *A. cristata* near Gananoque (L & G County, ON), ground- and water-based field surveys were undertaken from September through November 2014–2017 in the southern Frontenac Axis area. We investigated potentially suitable still, protected, open water sites in an approximately 1500-km² area within 25 km of the north shore of the St. Lawrence River between Kingston and Brockville. Several L & G County site visits were also conducted in July and early August 2015. These were unsuccessful, although *Azolla* plants were detected at

those sites later in the autumn of both 2014 and 2015 (Figures 1, 2, and 3; Table 1). Accordingly, mid-summer searches were not undertaken thereafter.

At each location, we conducted binocular-assisted visual surveys of creek and pond surfaces within 50–300 m of public roadways. Boat surveys also were conducted in September 2014 and 2016 along lower portions of the Gananoque River between Gananoque Lake and its outlet into the St. Lawrence River. Based on the strong association of *Azolla* populations with large mats of the aquatic Columbia Watermeal (*Wolffia columbiana* H. Karsten) and Northern Watermeal (*Wolffia borealis* (Engelmann) Landolt & Wildi ex Gandhi, Wiersema & Brouillet), we searched 15 large *Wolffia* mats evident from satellite imagery (GoogleEarth) on 8 November 2016 (Figure 4).

We collected voucher specimens for all distinct *A. cristata* populations discovered. These are deposited in herbariums at Agriculture and Agri-Food Canada (DAO), the Canadian Museum of Nature (CAN), the University of Guelph (OAC), the University of Manitoba (WIN), and/or D.F.B.'s personal herbarium (DFB). We reviewed the *Azolla* populations annually to determine their persistence. We also reviewed earlier herbarium voucher specimens in DAO, CAN, and the Royal Botanical Gardens (HAM) for additional records. In 2015 and 2016, we conducted informal interviews on



FIGURE 3. Dense, free-floating mat of brick-red Eastern Mosquito Fern (*Azolla cristata*) plants at Maple Grove, Gananoque River, Leeds and Grenville County, Ontario. Photo: D.F. Brunton, 5 October 2014.

Table 1. Summary of observations of Eastern Mosquito Fern (*Azolla cristata*) in Leeds and Grenville County, Ontario, Canada.

Year	Gananoque River (St. Lawrence River through Maple Grove to Marble Rock)		Sucker Brook, Maple Grove	Landon's Bay, St. Lawrence River	Knight's Creek, Ivy Lea	Gray's Creek, Front of Leeds and Gananoque Township
	Lower 10.8 km	Marble Rock				
2014	Abundant (deep drifts of plants at river mouth)	Abundant	—*	—	—	—
2015	None	Rare	—	—	—	—
2016	Abundant (no drifts)	Common	Common	Common	Abundant (forming drifts)	Rare
2017	Abundant (no drifts)	Common	None	—	Abundant	None

Note: Abundant = continuous mat; Common = scattered patches 0.5–2 m across; Rare = individual plants or small patches <30 cm wide.
*Not searched.



FIGURE 4. Locations of Eastern Mosquito Fern (*Azolla cristata*) in Leeds and Grenville County, Ontario. Circles = *Azolla* population (2014–2017); X = site where *A. cristata* was searched for but not found in suitable *Wolffia–Lemna* vegetation (2014–2017); broad vertical lines = approximate limit of Frontenac Axis; broad yellow [light] line indicates Canada–United States border. Numbers identify populations referred to in the text: 1, Gananoque; 2, Maple Grove; 3, Sucker Brook; 4, Gananoque River main channel; 5, Marble Rock; 6, Gray's Creek; 7, Landon Bay; 8, Knight's Creek. Base image: Gananoque, 44.406450°N, 76.091095°W, Google Earth Pro 7.3.1.4507. Imagery date: 3 July 2018. Accessed: 14 March 2019.

site with long-time residents to obtain historical information on particular sites and populations.

Azolla taxonomy and identification is complex, and that of *A. cristata* is particularly challenging, largely because of the rarity of sporocarp and megaspore production (Svenson 1944; Lumpkin 1993). All known *Azolla* specimens from eastern Canada are sterile. Their identification relies on subtle microscopic characters, such as leaf trichome shape. Trichomes of the typically smaller-leaved *A. cristata* are bi- to tri-cellular compared with unicellular trichomes in *A. filiculoides* (Evrard and Van Hove 2004). The latter species (and *A. mexicana*) also frequently produce sporocarps (Svenson 1944; Lumpkin 1993). The specimens in question

were examined in either a fresh or rehydrated condition through a light dissecting microscope (Wild M3B; Leica Microsystems, Wetzlar, Germany) at 40× magnification, with measurements made with the aid of an in-mount graticule (ocular micrometer).

Azolla cristata nomenclatural remains unsettled because of problems in interpretation of type specimens. Recent reviews of that problem conclude that *A. cristata* is the older, most appropriate name for this species (Evrard and Van Hove 2004; Pereira *et al.* 2011) and we follow that interpretation.

To assess the cold tolerance of *A. cristata*, plants from the Knight's Creek, L & G County population were collected in November 2016 and maintained in

cultivation over winter. One sample of approximately 20 floating fronds was kept in a container of creek water in a refrigerator at 4°C, and later became frozen in ice for approximately two weeks. A second, similar sample was maintained at approximately 17°C in the low natural light of a windowsill. Both were periodically examined through the winter season and into spring, with changes in size and appearance documented photographically.

Results

New eastern Ontario discoveries of Azolla cristata

In September 2014, *A. cristata* was discovered along the Gananoque River in L & G County in patches that were almost continuous for 10.8 km upstream from the St. Lawrence River (Figures 1, 2, and 3). Subsequently, persistent populations of *A. cristata* have been found along tributaries of the St. Lawrence River in five separate watersheds within an area of approximately 56 km² in southern L & G County (Figure 4). Locations include the main course of the Gananoque River and its tributary Sucker Brook. The other subwatersheds encompass Gray's Creek, Knight's Creek (Figure 5), and Landon's Bay, all of which empty directly into the St. Lawrence River.

New records of *A. cristata* found from 2014 to 2017 were all within the Frontenac Axis (Table 1; Figure 4), a rugged upland landscape of erosion-resistant Precambrian bedrock characterized by an abundance of water

bodies (Keddy 1995). In September 2014, we discovered large populations of *A. cristata* along the Gananoque River in patches extending from its confluence with the St. Lawrence River upstream for 10.8 km. The plants were conspicuous, forming large, dense, free-floating mats (Figure 3) suspended within a 5–10 mm thick growth of watermeal (*W. borealis* and *W. columbiana*), Small Duckweed (*Lemna minor* L.), Star Duckweed (*Lemna trisulca* L.), and Great Duckweed (*Spirodela polyrhiza* (L.) Schleiden). The brick-red colour of the *Azolla* patches was so conspicuous that the species was first noted from a vehicle moving at free-way speed on the Highway 401 bridge over the Gananoque River. In the Gananoque area, we observed the strong affinity of *Azolla* plants for *Wolffia* mats. Although some of the *Wolffia* mats examined did not support *Azolla*, all L & G County *A. cristata* populations were found amongst *Wolffia*.

In years of high abundance, *Azolla* was observed to grow in continuous expanses and was found in all the *Wolffia*–*Lemna* mats occupying side bays and shallow, quiet shore areas with reduced current along the lower Gananoque River. The *Wolffia*–*Lemna* mats remained continuously dense from the St. Lawrence River at Gananoque upstream for 10.8 km to Marble Rock. In some years, *A. cristata* plants and mat fragments piled up with millions of *Wolffia* plants into 10+ cm deep “drifts” on river obstructions and along the last several hundred metres of the Gananoque River shore in the



FIGURE 5. Portion of Knight's Creek Eastern Mosquito Fern (*Azolla cristata*) population (dark mat) in dense watermeal (*Wolffia* spp.) growth, Ivy Lea, Leeds and Grenville County, Ontario. Photo: D.F. Brunton, 10 November 2016.

town of Gananoque. The adjacent river shore at each site was distinguished by the great abundance of Tuckahoe (*Peltandra virginica* (L.) Schott & Endlicher), an otherwise provincially rare species (Oldham and Brinker 2009) with southern affinities (Toner *et al.* 1995).

Between September and November 2016, we also conducted searches for *Azolla* at 15 possible sites in southern L & G County where particularly large *Wolffia* mats were evident on GoogleEarth satellite imagery (Figure 4). Although these *Wolffia* mats appeared to be virtually identical in form, situation, and floristic association to the Gananoque River populations, we did not find any *Azolla* at these locations.

Overwintering of Azolla cristata

In our winter dormancy experimentation, refrigerated material from Knight's Creek failed to produce any new growth by late March (following a two-week freezing period). However, virtually all fronds from the second (room temperature) sample showed abundant new growth at the tips (Figure 6). Although the central axis of most of these plants was decaying, many bud tips were producing new growth, including several fragments that had already separated from the parent plant. The growth on most fronds, including fragments, continued vigorously into mid-April, at which time over half of most fronds constituted fresh green growth. It appears that *A. cristata* fronds, at least at room temperature, are capable of perennating from bud tips when those fronds persist in a dormant state throughout the winter months.

Discussion

Historical status of Azolla cristata in Canada

Azolla cristata has been recorded growing outside cultivation in Canada in BC, southern ON, and southern QC. The BC records are all recent discoveries in artificial and/or recently disturbed wetland habitats in the urbanized southwestern part of the province (lower mainland and adjacent Vancouver Island). With no previous history of occurrence in western North America (Lumpkin 1993), and its occurrence only in disturbed sites heavily used by humans, the BC populations are reasonably considered to represent anthropogenic occurrences (Klinkenberg 2017). At least some historical southern ON records, however, were considered likely to represent natural range expansions (Macoun 1890; Cody and Schueler 1988).

Azolla cristata was first collected in Canada at Burlington Beach (western Lake Ontario), ON in 1862 (Macoun 1890; Cody and Britton 1989). It was not reported again in Canada until 1981 when a large population was found at the mouth of Knight's Creek in L & G County near Gananoque. Robert Griffin (pers. comm. 27 September 2016) reported observations of large *A. cristata* populations along the Gananoque River between Gananoque Lake and Marble Rock settlement "every few years" since the late 1960s. Griffin in-

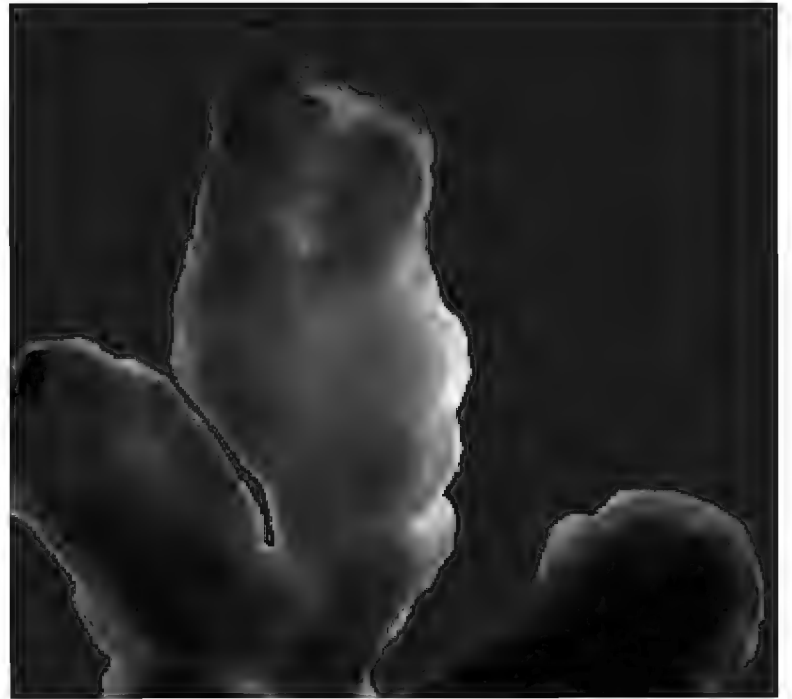


FIGURE 6. Pale-green-coloured, compressed, turion-like leaf-bundles (possibly winter buds) at tips of decaying Eastern Mosquito Fern (*Azolla cristata*) branches. Cultivated plants collected from Knight's Creek, Ivy Lea, Leeds and Grenville County, Ontario. Photo: H. Bickerton, 30 March 2017.

dependently identified the species at that location years previously but was unaware of its significance until advised during the present study. Although abundant in 1981 (Cody and Schueler 1988), and despite periodic site inspections through 2000 (D.F.B. pers. obs.), *A. cristata* was not observed again at Knight's Creek until 2016 (H.J.B. pers. obs.).

Darbyshire (2002) discovered *A. cristata* at several locations in Ottawa, ON, and Gatineau, QC, in both the Rideau Canal and Rideau River in both 1997 and 1998. In 1998, *A. cristata* was observed only along the Ottawa River. This occurrence extended semi-continuously for ~10 km of the Rideau River in ON and 5 km of the Ottawa River in ON and QC. It could not be found in follow-up site visits in 1999 but was reported again from that area in 2003 when a large population was found in a different area of the Rideau River (Darbyshire and Thomson 2004). Although waterfowl dispersal was regarded as a possible vector, the urban location of these occurrences suggested to those investigators that the 2003 occurrence most likely resulted from the dumping of home aquaria (Darbyshire and Thomson 2004).

Discoveries of short-lived *Azolla* occurrences (believed to be *A. cristata*) were made elsewhere in southern ON after 2000. These were found either in artificial or disturbed wetlands and/or following wetland vegetation planting of nursery stock plants, e.g., in the Royal Botanic Garden, Hamilton (C. Rothfels pers. comm. 17 March 2004), Oshawa Second Marsh, Durham Regional Municipality (D. Leadbeater and J. Kamstra pers. comm. September 2017), and Niagara Regional Municipality (A. Garofalo pers. comm. November 2016). Most represented small populations but some (e.g., Oshawa

Second Marsh) involved thousands of plants covering several hectares. None of these populations are believed to have persisted more than two years.

Origins and dispersal

Azolla cristata is abundant and perhaps increasing in abundance in wetlands in the Oswego, NY area, ~100 km directly south of the L & G County sites (A. Nelson pers. comm. 23 December 2014; E. Hellquist pers. comm. 1 May 2018). Indeed, it was known to be common, even abundant, in eastern Lake Ontario shore marshes as long ago as the mid-19th century (Paine 1865). *Azolla* is known from wetlands frequented by migratory waterfowl along the NY shore of the Great Lakes from St. Lawrence County (Eldblom and Johnson 2010) to the Niagara Frontier region (Soper 1949; Eckel 2005; Weldy *et al.* 2018).

Waterfowl are widely identified as the probable vector for both short and long distance movements of many aquatic plant species (Garcia-Alvarez *et al.* 2015; Coughlan *et al.* 2017). We frequently observed waterfowl, including Wood Ducks (*Aix sponsa*) and Canada Geese (*Branta canadensis*), loafing or preening in *A. cristata* patches along the Gananoque River, the former also apparently feeding among beds of *Azolla* and *Wolffia*. In October 2016, we observed plants adhering to the breast feathers of free-ranging Mute Swans (*Cygnus olor*) that were swimming through dense *Azolla* at the mouth of the Gananoque River. *Lemna* spp., a major constituent of the *Wolffia*–*Lemna* mats favoured by *A. cristata*, are known as a preferential, high-nutrient food source for waterfowl in general and swans in particular (Lumsden *et al.* 2017).

Costea *et al.* (2016) suggest that transport of plant propagules by waterfowl (internally) represents an underappreciated long-distance movement mechanism for various species in North America and indeed, Lovas-Kiss *et al.* (2018) document the long-distance transport of viable *Azolla* relative Floating Fern (*Salvinia natans* (L.) C. Allioni) macrospores in Europe. Similarly, Cranfill (1980) suggested that *A. cristata* populations in Kentucky may result from repeated introductions by migrating waterfowl. The suggestion by Cody and Schueler (1998) that such a process could explain the long periods of time between *Azolla* observation at Knight's Creek, L & G County, is supported by the distribution and habitat patterns noted here for both *Azolla* and waterfowl. Accordingly, dispersal by waterfowl from adjacent northern NY also seems the most plausible explanation for the comparable mass occurrences of *A. cristata* in L & G County and elsewhere in eastern ON and western QC.

The local distribution of *A. cristata* within individual waterways may also benefit from the physical transport of propagules by external agents. A large (0.6-ha) floating section of marsh turf consisting of Cattail (*Typha latifolia* L.) lifted off from the adjacent Wiltse Creek marsh in 1981 and blocked the section of the Gananoque River where *A. cristata* mats has been periodically

observed since the 1960s. Smaller examples of such sediment-gouging marsh vegetation “rafts” occur sparingly but regularly along the river (R. Griffin pers. comm. 27 September 2016). Although no *Azolla* were observed during an 18 September 1981 investigation of the marsh blockage (Brunton 1981), such rafting could be responsible for the periodic downstream transport of *Azolla* plants.

It seems unlikely that the dumping of aquarium waste could explain recurring, independent populations of *A. cristata* across five subwatersheds in this lightly or uninhabited Canadian Shield landscape of L & G County. Indeed, *A. cristata* appears to be infrequently or rarely cultivated as a water garden or aquarium species in Canada, even in heavily urbanized areas. An online survey of 365 nurseries and aquaria active in the Greater Toronto Area (GTA) between 2011 and 2013 found that only 17 (4.6%) offered this species (L. Erdle pers. comm. 2017). Azan *et al.* (2015) reported that of 331 857 individual plant sales in one year by 20 stores in the GTA, only 931 (or 0.003%) consisted of *A. cristata* (as *A. caroliniana*).

Extent and persistence of populations

Some of the newly discovered L & G County *Azolla* populations were found to be immense, covering many hectares (Figure 3), in one case extending for kilometres. In 2016, we conservatively estimated a density of 13.5 *Azolla* plants/m² in a typical *Wolffia*–*Lemna* mat at the Maple Grove settlement ($n = 20$ randomly chosen, 1-m² plots). Thus, this 2.6-km stretch of the Gananoque River that includes about 36 ha of apparently suitable habitat (identified from satellite images), supports about 485 000 plants. Extrapolating to the entire 10.8-km section of the Gananoque River along which *Azolla* was found implies an *Azolla* population of about two million plants. Even this large number, however, reflects only a portion of the total population that year because it excludes smaller sites off the Gananoque River. Despite that impressive estimate, in 2014 our field observations indicate that *Azolla* populations were even larger near the town of Gananoque—likely 200–300% more dense.

Azolla cristata has been considered short lived in the north of its range (Crow and Hellquist 2000). Populations in upstate NY appear to follow that pattern, persisting for several years in a given location, then disappearing for at least a period of years (A. Nelson pers. comm. 23 December 2014). Our finding that *A. cristata* has persisted at individual sites in L & G County for several years and probably even decades (R. Griffin pers. comm. 27 September 2016) is therefore notable. The Knight's Creek population, for example (Figure 5), has been known from its present location since at least 1981 (Cody and Schueler 1988; F.W. Schueler pers. comm. 6 November 2016). Despite periodic inspection in the intervening years (D.F.B. pers. obs.), *Azolla* was not observed again until 2016 (H.J.B. pers. obs.).

Overwintering capacity

The existence of these recurring *A. cristata* populations strongly suggests persistence over winter, either as dormant plants from the previous year or through the survival of propagules. This is consistent with observations near Lake Erie where a population believed to be *A. cristata* persisted over at least two growing seasons (2006 and 2007) in Black Creek (Fort Erie, ON; A. Garofolo pers. comm. 19 December 2016) and along the Rideau River in Ottawa in the late 1990s (Darbyshire 2002). Eric Hellquist (pers. comm. 28 May 2018) reports that *Azolla* plants in central NY were evident in May 2018 at a site where the species is reliably found; this is too early in the growing season for these plants to represent growth from the current year.

Azolla cristata was presumed unable to endure Canadian winter conditions, based on its apparent lack of persistence in ON (Darbyshire 2002). Because the -11°C average lowest winter temperature of Gananoque (Weather Spark 2018a) is only 3°C below the -8°C average lowest winter temperature of Oswego, NY (Weather Spark 2018b) where *A. cristata* is common (E. Hellquist pers. comm. 28 May 2018), “Canadian winter conditions” may not actually present a significant constraint to *Azolla* population sustainability in L & G County. The lower section of the Gananoque River where *Azolla* has been abundant in recent years was unfrozen on 2 March 2019 (D.F.B pers. obs.), also implying that aquatic temperature conditions are relatively moderate here.

Wong Fong Sang *et al.* (1987) found that *A. filiculoides* plants, frozen in a wild state between -10°C and -1°C for at least two weeks and then transferred to a 25°C growth chamber, started to grow again. Fronds of *A. filiculoides* are reportedly able to withstand hard frosts (-5°C) and prolonged ice cover (Lumpkin and Plucknett 1980). Janes (1998) found that although mature *A. filiculoides* plants in England died following a short (18 h) exposure to -4°C temperatures, they were capable of surviving encasement in ice for at least a week and only those plants that protruded above the ice were killed at sub-zero temperatures. Because *Azolla* can survive indefinitely at 4°C , Janes (1998) suggested that plants are capable of survival in fresh water below the ice where the temperature does not reach 0°C .

Azolla cristata is thought to be among the most cold-tolerant members of its genus (Lumpkin 1993). Consistent with that, in this study mats of apparently healthy *A. cristata* were evident at Knight’s Creek on 9 November 2016 in 6°C water. Robust populations also were noted at Kinsman Park in Gananoque even later into that year on 19 November 2016 (K.L. McIntosh pers. comm. 19 November 2016).

We found no reference to turion-like structures in *A. cristata* in the botanical literature, although based on the growth observed in our cultivated sample (Figure 6; also see Results), these appear to exist. Eric Hellquist (pers. comm. 28 May 2018) also observed what appears

to be perennating bud tips in *Azolla* populations in central NY in early May.

Conclusions

There is substantial evidence that *A. cristata* is naturally occurring in the Frontenac Axis of L & G County, ON. Large populations have persisted for 20+ or even 50+ year periods in lightly settled, rural locations there far removed from urban and suburban centres. Our observations, along with a reinterpretation of the earlier eastern ON and western QC data of Darbyshire (2002) and Darbyshire and Thomson (2004), imply that human-facilitated introductions are unlikely here. Interpretation of the likely origins of populations in the western Lake Ontario area is less clear because of their frequent occurrence in disturbed areas with high population densities.

The long period between observations of *Azolla* at some L & G County sites may not represent true absences, but may reflect periods when poorer growing conditions result in smaller, inconspicuous populations. The tiny population along the Gananoque River in 2015 between two “bumper” years, for example, could be a reflection of the documented ephemeral nature of *A. cristata* (Svenson 1944; Cranfill 1980; Lumpkin 1993). Small, inconspicuous populations may be normal in ON and elsewhere, with extensive populations such as those noted along the Gananoque, Ottawa, and Rideau Rivers, appearing only in years of especially favourable growth.

The occurrence of apparently self-sustaining *A. cristata* populations in eastern ON has phytogeographic and conservation implications. These occurrences are located within suggested plant migration routes of other uncommon plants with southern affinities. The Frontenac Axis area has long been recognized as a centre for such diversity, including provincially rare plant taxa of conservation concern, such as Pitch Pine (*Pinus rigida* P. Miller), Deerberry (*Vaccinium stamineum* L.), Appalachian Polypody (*Polypodium appalachianum* Hauffler & Windham), Rue-anemone (*Thalictrum thalictroides* (L.) A.J. Eames & B. Boivin), and *Azolla* associate *P. virginica* (Dore *et al.* 1959; Cody 1982; Keddy 1995; Oldham and Brinker 2009).

Warming weather conditions in recent decades may be encouraging the persistence of *Azolla* populations in ON, QC, and BC. Warmer winters with longer ice-free periods and slightly warmer water temperatures would be expected to suppress barriers to the establishment and persistence of particular populations. The increased number of potential animal vectors in recent decades (especially migratory Wood Ducks and Canada Geese; Hughes and Abraham 2007; Zimmerling 2007) also increases potential opportunities for *Azolla* to be repeatedly transported into southeastern Canada.

Author Contributions

Both authors contributed to the conceptualization of this article, investigation, methodology, formal analysis

of the data, writing of the original draft, review and editing. Both authors approved the final version of the manuscript.

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Distribution and taxonomy of *Isoetes tuckermanii* subsp. *acadiensis*, comb. nov. (Isoetaceae) in North America

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Abstract

Isoetes acadiensis is an emergent aquatic lycophyte of freshwater shores found in a narrow range along the Atlantic coast of northeastern North America where it frequently coexists with *Isoetes tuckermanii* (*sensu stricto* [*s. str.*]). Apparently fertile plants with intermediate morphology occur commonly in mixed populations. No sterile hybrids between the two taxa have been detected. Although *I. acadiensis* maintains a distinctive geographic distribution (within and smaller than that of *I. tuckermanii* [*s. str.*]), exhibits molecular evidence of genetic distinctiveness, and has morphologically distinctive features in most populations, the weight of evidence suggests it is not distinct from *I. tuckermanii* at a species level. Accordingly, *I. tuckermanii* subsp. *acadiensis*, comb. nov. is proposed as the appropriate designation for this biogeographically important Acadian endemic.

Key words: *Isoetes tuckermanii* subsp. *acadiensis*; *Isoetes acadiensis*; *Isoetes tuckermanii*; taxonomy; distribution; Acadian endemic; lycophyte

Introduction

Interspecific relationships within the lycophyte group Quillworts (*Isoetes*; Isoetaceae) have received considerable attention in North America since the 1980s (Kott and Britton 1983; Taylor and Luebke 1988; Taylor *et al.* 1993; Brunton and Britton 1997; Musselman *et al.* 1997; Brunton and McNeill 2015). However, the infraspecific relationships of these *Isoetes* have received less attention because of the group's reputation for difficult identification (Tryon and Tryon 1982; Cody and Britton 1989). Subspecific classification is applied to separate the common North American *Isoetes echinospora* M. Durieu subsp. *muricata* (M. Durieu) A. Löve & D. Löve (Taylor *et al.* 1993) from Eurasian *I. echinospora* (*sensu stricto* [*s. str.*]) populations, but only one North American *Isoetes* subspecies has been described in recent years: *Isoetes melanopoda* M. Durieu subsp. *silvatica* D.F. Brunton & D.M. Britton in the southern United States (Brunton and Britton 2006; Troia and Rouhan 2018).

Acadian Quillwort, *Isoetes acadiensis* L.S. Kott, was separated from *Isoetes tuckermanii* A. Braun (Kott 1981) during a period of particularly dramatic re-evaluation of the genus in North America (Brunton and Troia 2018). Since that time, increases in the quantity and quality of *Isoetes* field data in North America have enhanced taxonomic clarity within the group in general and the *I. tuckermanii* – *acadiensis* complex in particular.

Recent distributional, morphological, and ecological evidence suggests that *I. acadiensis* may not be specifically distinct from *I. tuckermanii*. In some recent publications these taxa have been combined without nomenclatural distinction (Taylor *et al.* 2016). Based on extensive field and herbarium studies over several dec-

ades supported by enhanced and more abundant imagery than was available in the past, this study evaluates that concept and presents evidence for a reconsideration of the taxonomic status of *I. acadiensis*.

Methods

Kott (1981) identified three attributes that distinguish *I. acadiensis* from *I. tuckermanii*: megaspore and microspore ornamentation patterns and leaf colour. Over 300 herbarium specimens were examined for these and other definitive morphological and/or ecological attributes. Other features that have been useful in discriminating closely related *Isoetes* taxa, such as plant size, root and corm form and structure, spore size and colour, velum coverage of the sporangia, and sporangial pigmentation (Taylor *et al.* 1993, 2016; Brunton 2015), were found not to differ between *I. acadiensis* and *I. tuckermanii* (*s. str.*) (Kott 1981; Kott and Britton 1983; this study) and were not evaluated further.

Between 1989 and 2017, I examined 33 *Isoetes tuckermanii* (*sensu lato* [*s. l.*]) populations in the field in New Brunswick (NB), Newfoundland and Labrador (NL), Nova Scotia (NS), including the *I. acadiensis* type location, Ontario (ON), Connecticut, Maine (ME), Massachusetts (MA), and New Hampshire. These observations provide insight into the site ecology, population structure, and infraspecific abundance within individual populations throughout the range of the taxon.

Scanning electron microscope (SEM) images were taken of microspores and megaspores of selected specimens of *I. tuckermanii* (*s. l.*) from contemporary collections and herbarium specimens using the standard methods of Britton and Brunton (1992) and Brunton and Britton (2006). Herbaria reviewed for *I. tuckermanii* and related taxa include Acadia University (ACAD),

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Canadian Museum of Nature (CAN), Agriculture and Agri-Food Canada (DAO), Duke University (DUKE), University of Michigan (MICH), Milwaukee Public Museum (MIL), Missouri Botanical Garden (MO), Université de Montréal (MT), University of New Hampshire (NHA), Nova Scotia Museum of Natural History (NSPM), New York Botanical Garden (NY; selected specimens), New York State Museum (NYS), University of Guelph (OAC), Academy of Natural Sciences (PH), and author's private collection (DFB).

The concept of subspecies employed here is consistent with the traditional view of it as a geographically coherent component of a species with morphological distinctions that can intergrade (Davis and Heywood 1963; Kapadia 1963; Mayr and Ashlock 1991). This is more explicitly defined by USDA (2010) as “a grouping within a species used to describe geographically isolated variants, a category above variety”.

The infraspecific term “variety” was used widely in earlier North American *Isoetes* literature (Engelmann 1867, 1882; Proctor 1949; Reed 1953). It was applied rather loosely however, to geographically randomized morphological variants; most of these have subsequently been synonymized or dismissed as forms. Article 25 of the International Code of Nomenclature (Shenzhen Code) states that varieties are components of subspecies but not equivalent to them (Turland *et al.* 2018).

Results

Isoetes tuckermanii is a locally common tetraploid ($2n = 4x = 44$), shallow-water aquatic/emergent of freshwater lake and river shores in northeastern North America (Taylor *et al.* 1993), growing in acidic or sub-acidic substrates. *Isoetes acadiensis* (also tetraploid) was distinguished from *I. tuckermanii* by Kott (1981) based on several key characters:

- megaspore ornamentation—lower, broader muri (Figure 1a) in a more open pattern than with *I. tuckermanii* (Figure 1b) and completely lacking the latter's equatorial band (girdle) of spines;
- microspore ornamentation—a densely echinate or coarsely papillate perispore (surface; Figures 2a,b) compared with a smooth to densely fine-papillate perispore in *I. tuckermanii* (Figures 2c,d);
- leaf colour—darker green, rarely exhibiting the reddish-brown colour typical of *I. tuckermanii*;
- restricted distribution—confined to a narrow band along the Atlantic coast (Figure 3).

Morphological variation and genetic distinction

Field and herbarium research undertaken in the current study indicates that several of the stated *I. acadiensis* attributes are also common in *I. tuckermanii* (*s. str.*) populations. Leaf colour, for example, was found to be uniformly reddish-brown in all 18 mixed populations (several thousand plants) examined *in situ* in NS and NB, including those at the type location for *I. acadiensis* in Halifax County, NS (Figure 4). Extensive examinations of SEM images obtained since 1981 have also determined that, although *I. acadiensis* plants routinely exhibit the densely echinate microspore ornamentation described in Kott (1981), such ornamentation is also frequently found on plants with typical *I. tuckermanii* megaspore ornamentation (e.g., Lake George, York County, NB, D.M. Britton and A. Anderson 11,915, [OAC]). Conversely, the smooth to papillate microspore ornamentation typical of *I. tuckermanii* is found on plants with typical *I. acadiensis* megaspore ornamentation (e.g., Uniake Lake, Hants County, NS, M.L. Fernald *et al.* 23,107 [GH] and Trefry Lake, Yarmouth County, NS, M.L. Fernald *et al.* 19,618, [NSPM]). Some *I. tuckermanii* (*s. l.*) specimens

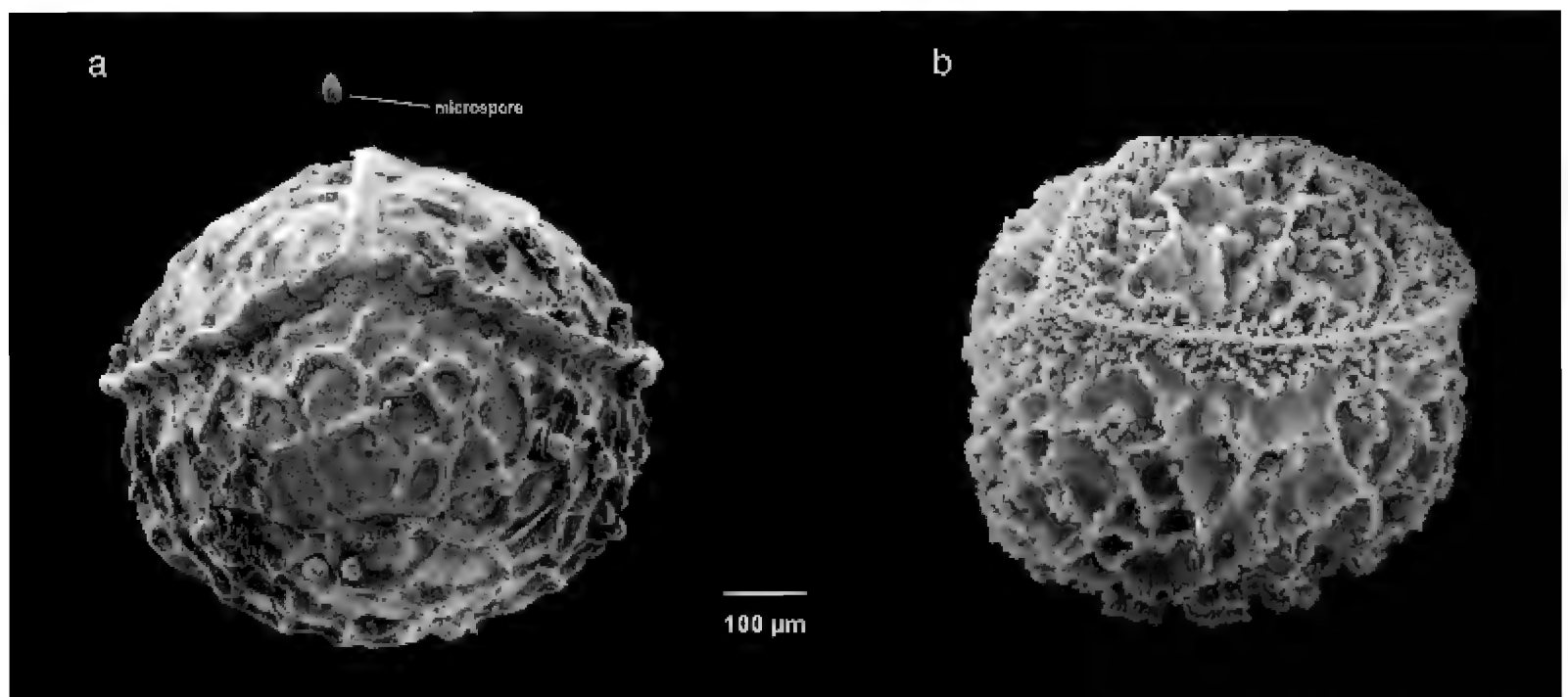


FIGURE 1. Typical megaspores of *Isoetes tuckermanii* (*s. l.*). a. *I. acadiensis*, Grand Lake Shubenacadie, Halifax County, Nova Scotia, R. Bidwell s. n., 11 August 1945 (Topotype) (NYPM); b. *I. tuckermanii* (*s. str.*), Taunton, Massachusetts, A.A. Eaton s. n., 15 September 1903 (MICH). Photos: Donald M. Britton.

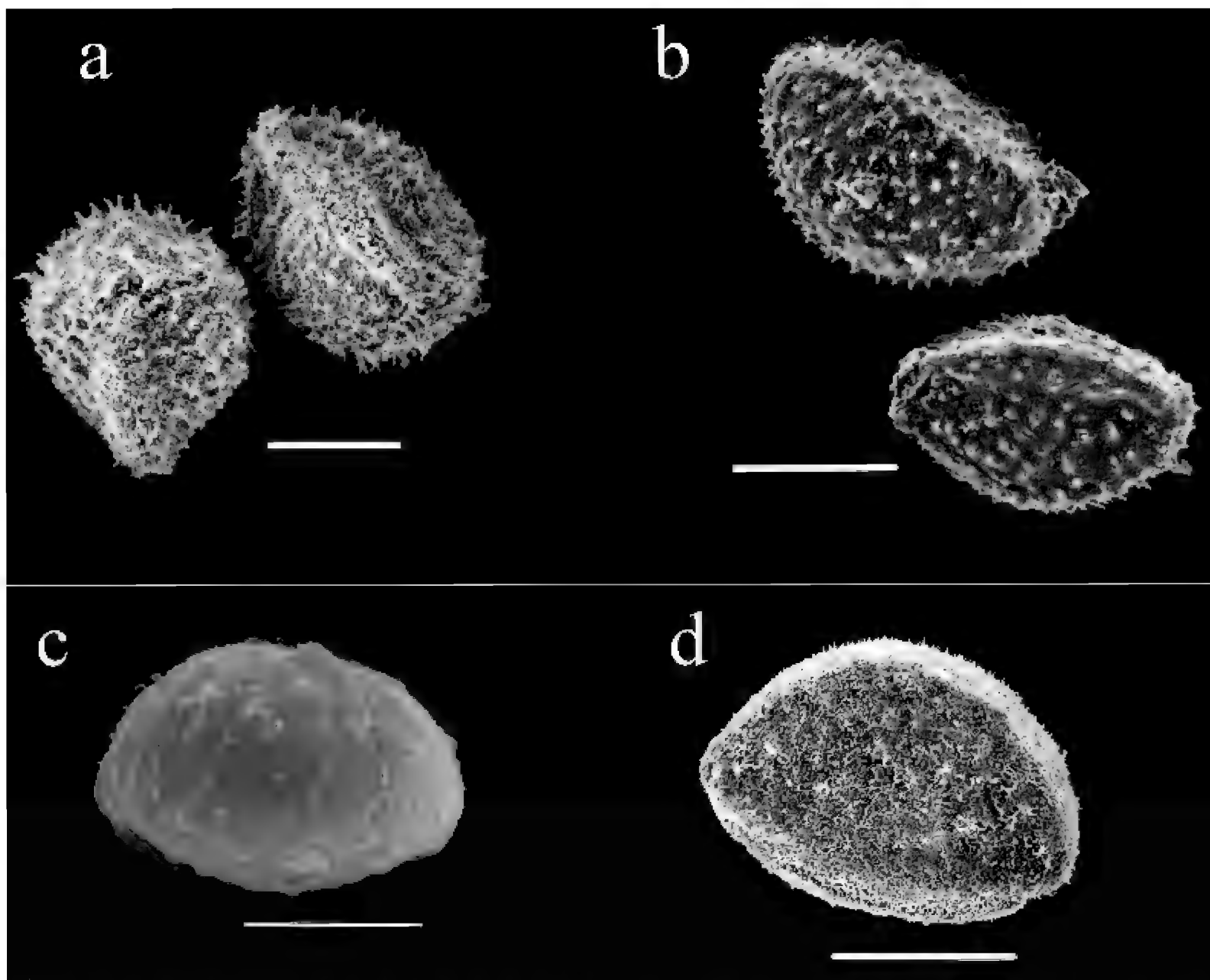


FIGURE 2. Typical microspores of *Isoetes tuckermanii* (s. l.). *I. acadiensis*: a. Short papillate-echinate type (Gavelton, Yarmouth County, Nova Scotia [NS], M.L. Fernald, B. Long & D.H. Linder 19,626, 4 August 1920 [NSPM]); b. Roughly echinate type (Grand Lake Shubenacadie, Halifax County, NS, R. Bidwell s. n., 11 August 1945 [NYPM]). *I. tuckermanii* (s. str.): c. Plain to smooth type (Taunton, Massachusetts, A.A. Eaton s. n., 15 September 1903 [MICH]); d. Densely fine-papillate type (Gray Lake, Muskoka District, Ontario, J. Goltz and P. Papoulidis 1,447, 11 August 1988 [OAC, DFB]). Scale bar = 10 μ m. Photos: Donald M. Britton.

were found to contain microspores with both smooth to papillate and densely echinate ornamentation patterns (Figure 5). Consistent with most other polyploids in North America (Taylor *et al.* 1993; pers. obs.), no significant differences in megaspore or microspore size were detected between these two tetraploids (Kott and Britton 1983; this study).

That said, the extremes of megaspore ornamentation expression between *I. tuckermanii* (s. str.) and *I. acadiensis* can be dramatic, with the low, broad muri and a plain, unornamented equatorial band (girdle) typical of *I. acadiensis* (Figure 1b) contrasting sharply with the thin, high-walled muri and dense band of equatorial spines of *I. tuckermanii* (s. str.) (Figure 1a). Even this characteristic is ambiguous, however. I have found that many plants (a majority in some cases) in at least eight of 21 Canadian *I. acadiensis* populations considered to be that taxon on the basis of other characters to exhibit intermediate megaspore ornamentation (Figure 6).

No plants with the aborted megaspores indicative of sterile hybrids (Taylor and Luebke 1988; Britton and Brunton 1989, 1992) have been detected in mixed *I. acadiensis*–*I. tuckermanii* populations. Similarly, aborted megaspores have not been observed amongst the numerous (200+) plants with intermediate megaspore and/or microspore ornamentation observed in this study.

Strikingly, however, plants with typical *I. acadiensis* megaspore ornamentation as per Kott (1981) appear to be almost entirely confined to the Acadian region of northeastern North America (viz., the Maritime provinces of Canada and the adjacent northeastern United States; Figure 3).

Megaspore ornamentation patterns of particular populations remain true to form over many years. An example of this is provided by the consistent megaspore ornamentation pattern exhibited by *I. acadiensis* plants in Trefry Lake, Yarmouth County, NS, over the last century, starting in 1920 (M.L. Fernald & B. Long 19,614

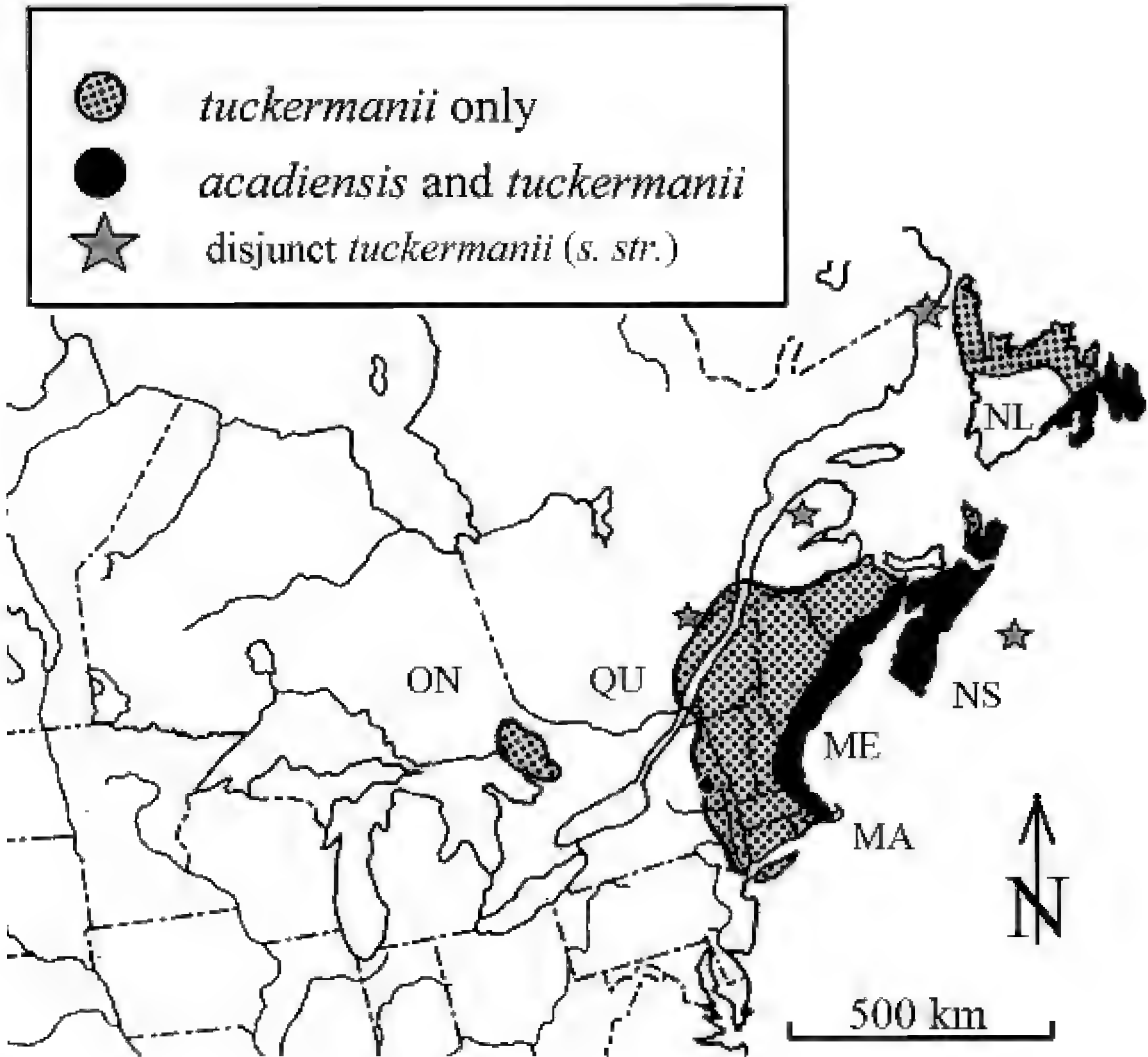


FIGURE 3. Distribution of *Isoetes tuckermanii* (s. l.) in North America (adapted from Taylor *et al.* 1993).



FIGURE 4. *Isoetes acadiensis* plants at type location, Grand Lake Shubenacadie, Halifax County, Nova Scotia, 18 July 2016. Coin is 27 mm across. Photo: D.F. Brunton.

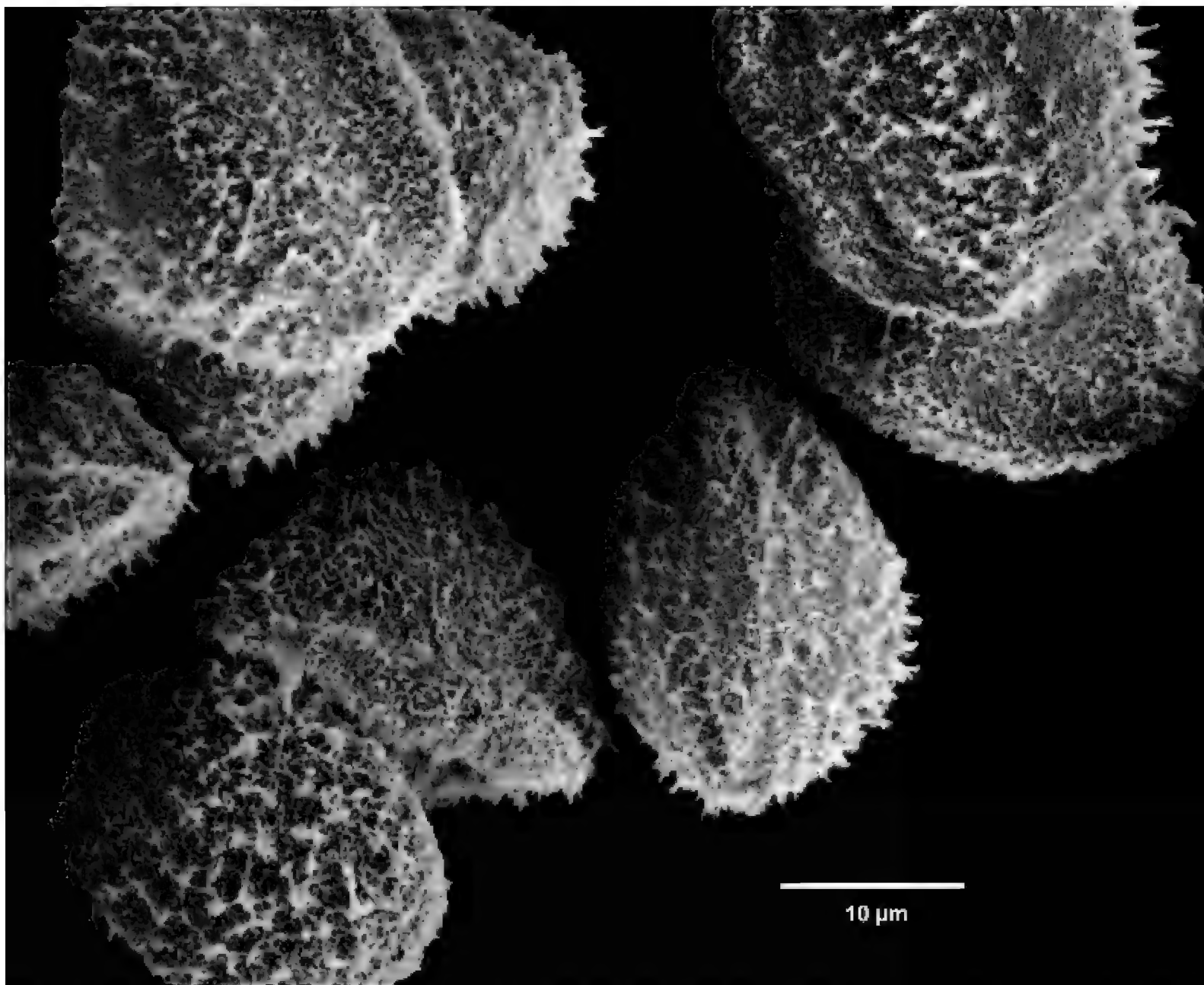


FIGURE 5. *Isoetes tuckermanii* (s. l.) microspores on a single plant with intermediate ornamentation ranging from finely papillate *I. tuckermanii* (s. str.) type (top left) to coarsely echinate *I. acadiensis* type (below, left, and right); Tusket River, Yarmouth County, Nova Scotia, J.S. Erskine 51.1436, 28 August 1951 [NSPM]). Photos: Donald M. Britton.

[NSPM]) through 1995 (D.F. Brunton and K.L. McIntosh 12,342 [OAC, DFB]) to 2015 (D.F. Brunton and K.L. McIntosh 19,400 [NY, DFB]). Currently however, plants showing megaspore ornamentation intermediate between “classic” *I. acadiensis* and *I. tuckermanii* (s. str.) appear to be the most commonly represented individuals at this site (pers. obs.).

Genetic evidence in support of particular taxonomic interpretations is unclear and perhaps contradictory. Based on DNA sequencing, Hoot *et al.* (2004) found a subtle but evident genetic distinction between *I. tuckermanii* (s. str.) and *I. acadiensis*. That study also found that despite a substantial (~800 km) oceanic gap between the two, genetic affinities (shared parental genomes) were evident between *I. acadiensis* and the European *Isoetes azorica* M. Durieu. Based on morphological characteristics, this relationship was alluded to earlier by Britton and Brunton (1996; see also Discussion, below). Recent data from contemporary Next Gen sequencing also suggests that insufficient justification exists for the treatment of *I. acadiensis* as specifically distinct from *I. tuckermanii* (P. Schafran pers. comm.

July 2018). In contrast, however, the sequence data reported by Pereira *et al.* (2018) suggests species status distinctions based on different origins for *I. acadiensis* and *I. tuckermanii* (s. str.).

Isoetes acadiensis is reported as being of disjunct occurrence in brackish marshes in eastern Virginia, there providing the tetraploid parent for the sterile triploid ($2n = 3x = 33$) hybrid *I. ×carltaylorii* L.J. Musselman (*I. acadiensis* × *engelmannii* A. Braun). The tetraploid taxon involved in this hybrid, however, appears to be *Isoetes riparia* M. Durieu var. *reticulata* A.A. Eaton, a rare Atlantic coastal taxon with atypically subdued megaspore ornamentation which mimics that of *I. acadiensis* (Brunton 2015). *Isoetes acadiensis* has not otherwise been reported south of MA, 650 km to the north.

Decaploid ($2n = 10x = 110$) *Isoetes lacustris* L. forma *hieroglyphica* (A.A. Eaton) W.N. Clute is confused with *I. acadiensis* as well. It has megaspores ornamented with low, broad muri and a plain, unornamented equatorial band (Kott and Britton 1983; Tryon and Moran 1997; Haines 2011). The former is identical in all other respects to *I. lacustris* (s. str.) however. Most importantly,

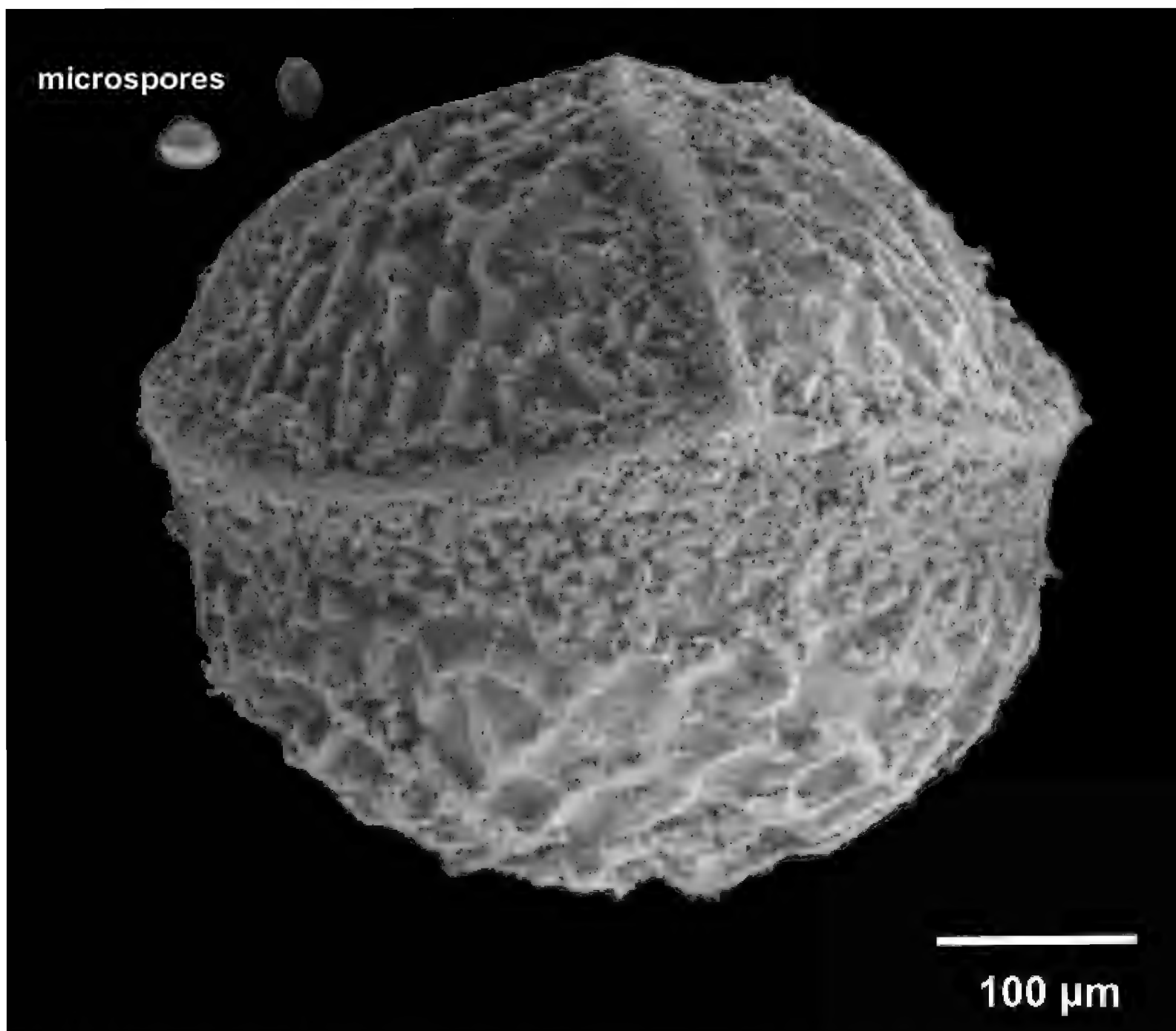


FIGURE 6. *Isoetes tuckermanii* (*s. l.*) with intermediate megaspore ornamentation, exhibiting the equatorial band of spines of *I. tuckermanii* (*s. str.*) and the lower, broader, less congested distal muri of *I. acadiensis* (Jassy Lake, Yarmouth County, Nova Scotia, R.C. Bean, D. White and D.H. Linder 19,615, 29 July 1920 [NSPM]). Photos: Donald M. Britton.

decaploid forma *hieroglyphica* has much larger (≥ 650 μm) megaspores than those (~ 520 μm) of tetraploid *I. tuckermanii* (*s. l.*) (Kott and Britton 1983; Taylor *et al.* 2016). Although found predominately in the Maritime provinces of Canada and adjacent New England, forma *hieroglyphica* rarely if ever forms pure populations and is found randomly across most of the range of *I. lacustris* (*s. l.*) as far west as central ON (Boshkung Lake, Stanhope Township, Haliburton County, ON, D.F. Brunton, K.L. McIntosh, W.C. Taylor & C.A. Caplen 13,349C, 9 August 1997 [OAC]).

Ecological segregation

Although plants of *I. acadiensis* and *I. tuckermanii* (*s. str.*) were most often found randomly in the 18 mixed populations examined in this study, some habitat differentiation has been noted. Transects conducted across large mixed populations in Yarmouth County, NS, in 1990, for example, indicated that plants with *I. acadiensis* megaspore ornamentation patterns occurred dis-

proportionately in very shallow water or on emergent shores, while those with *I. tuckermanii* megaspore ornamentation patterns most commonly occurred in deeper water (0.5–1 m; pers. obs.). However, an exactly reversed situation was observed along similar transects conducted in mixed populations in Barnstable and Plymouth Counties, MA, in 1989 (pers. obs.). Accordingly, while some ecological segregation appears to be occurring within individual populations, no consistent pattern has been established.

Discussion

The herbarium, SEM, and field investigations described above, as well as most of the molecular evidence noted here, suggest that *I. acadiensis* constitutes a genetically distinct taxon (with European affinities) within *I. tuckermanii* (*s. l.*) and is almost exclusively confined within a restricted geographic range. A collection from Stoner Lake, Fulton County, New York (R.T. Clausen 5518, 17 August 1941 [NYS]) represents the only sig-

nificantly inland report of this taxon (Figure 3). This distributional evidence, the absence of diagnostic morphological characters, ambiguous genetic evidence, and the apparent absence of sterile hybrids within populations that frequently (more than 60%) are mixed, indicate that *I. acadiensis* is not specifically distinct from the more wide-ranging *I. tuckermanii* (s. str.). The available evidence suggests that a subspecific ranking is the most appropriate designation for this taxon; that is proposed here.

Isoetes tuckermanii A. Braun **subsp. acadiensis** (L.S. Kott) D.F. Brunton, **comb. et stat. nov.**

Basionym: *Isoetes acadiensis* L.S. Kott; Canadian Journal of Botany 59: 2592. 1981.

Isoetes tuckermanii subsp. *acadiensis* may represent a relatively recent evolutionary “experiment” dating from the Wisconsinan or middle Sangamonian continental glaciation period (<110 000 years before present). During this period, extensive areas of the now-submerged continental shelf were exposed and available for colonization by coastal plain taxa (Fulton 1989). The identification of genetic affinities of *I. tuckermanii* subsp. *acadiensis* with *I. azorica* by Hoot *et al.* (2004) supports this, suggesting the former might once have occurred across a much larger area of the exposed continental shelf coastal plain. Accordingly, it likely was considerably more common at that time than it is today. Comparably, the rare Acadian quillwort endemic *Isoetes prototypus* D.M. Britton (Britton and Goltz 1991), may also have been more widely distributed across that larger glacial era Atlantic coastal plain.

Individual *I. tuckermanii* subsp. *acadiensis* populations are large—often consisting of hundreds or even thousands of plants (pers. obs.)—but it is found in relatively few individual populations overall. It is accordingly designated to be of conservation concern in NL (S1), NB (S2S3), NS (S3), ME (S2), and MA (S1) (NatureServe 2019). In addition to this significance, the taxon presents considerable potential for evolutionary and biogeographic research.

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Seasonal and temporal variation in scaled mass index of Black-capped Chickadees (*Poecile atricapillus*)

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Abstract

Avian body mass reflects a trade-off between risk of starvation and predation, and may vary with ambient temperature, age, and time of day. Seasonal variability in body mass is a common occurrence in northern temperate regions, including adaptive fattening. Previous evidence suggests that seasonal variability is less pronounced in tree-feeding bird species, as their food sources during winter are less limited and variable compared to ground-foraging species. We determined fat scores of tree-feeding Black-capped Chickadees (*Poecile atricapillus*) captured year-round between 2004 and 2015 ($n = 4248$) in southern Quebec, to test the relative strength of possible drivers of variability in chickadee body mass, including time, date, and year of capture, age, and temperature. First, we demonstrated that scaled mass index (SMI) was the body condition index, out of four possible indices tested, which most strongly correlated with fat scores measured in the field. We used SMI subsequently as our estimator of body condition to avoid observer effects associated with fat scores. Similar to other studies, time of capture significantly affected SMI, in which birds captured later were heavier, indicating that chickadees experience overnight weight loss and subsequent weight gain from foraging throughout the day. SMI was constant from April to November, then peaked in late winter, but was not influenced by daily temperature after accounting for month and year. SMI was not significantly affected by age. We concluded that adaptive fattening is an evolutionary response to risk of starvation in winter, rather than a proximal response to immediate ambient temperature.

Key words: Black-capped Chickadee; condition index; fat stores; scaled mass index; temperature; temporal; body mass

Introduction

Body mass varies greatly within bird species, often representing variation in lipid mass, and reflecting costs and benefits to high lipid stores (Lindstedt and Boyce 1985; Cresswell 1998). Higher lipid deposits may increase survival during periods of food shortage because fatter individuals have more endogenous energy stores (Thomas 2000; Krams *et al.* 2009; Ratikainen and Wright 2013). In winter, these energy stores may also act as buffers against cold temperatures, as birds expend more energy for thermoregulation, as well as against short winter days when reduced foraging increases the risk of starvation (Brodin *et al.* 2017; Da Silva *et al.* 2017). However, costs to higher body mass due to higher lipid deposits may include reduced takeoff ability and more time spent foraging to maintain a high body mass, both of which can increase chances of predation (Gosler *et al.* 1995; MacLeod *et al.* 2005, 2008; Rogers 2015). Alternatively, variation in lipid deposits may be stress-induced rather than adaptive; a lower average body mass may reflect low food availability rather than a fitness optimum (Ketterson *et al.* 1991; Kitaysky *et al.* 1999).

In northern temperate regions with large climate ranges, the effect of seasonality on body mass is especially pronounced (Haftorn 1992; Rogers 1995; Cooper 2007; Polo *et al.* 2007). The concept of adaptive winter fattening, in which small birds residing in cold

habitats build up large fat reserves in response to low temperatures, has been widely studied (Haftorn 1989; Rogers 1995; Koenig *et al.* 2005; Merom *et al.* 2005) since its introduction by King and Farner in 1966. Weight gain in winter is caused by increased lipid deposits, which provide the metabolic fuel required to sustain an individual during winter fasts or food shortages (Lehikoinen 1987), as well as enlarged organs and muscles (Liu *et al.* 2008; Zheng *et al.* 2008, 2010; Liknes and Swanson 2011). Body mass tends to peak in mid-winter and decline thereafter (Haftorn 1989). Lower body mass in spring and summer may be attributed to physiological stress during the breeding season or adaptive reduction in wing-loading to ease the labour of feeding nestlings (Freed 1981; Nagy *et al.* 2007). Other temporal factors that affect body mass include diurnal variation and migration (Winker *et al.* 1992; Cresswell 1998; Schaub and Jenni 2000).

Black-capped Chickadee (*Poecile atricapillus*), a tree-foraging species, overcomes the hardships of winter by caching its resources (Sherry and Vaccarino 1989), relying on micro-climates (Cooper and Swanson 1994), undergoing facultative diurnal hypothermia (Lewden *et al.* 2014), and increasing breast muscle size and enzymatic activity to improve shivering thermogenesis (Liknes and Swanson 2011). In ground-foraging birds, the trend of adaptive winter fattening holds true for several species, including juncos and sparrows (King

and Farner 1966; Newton 1969; Rogers 1995), which those authors argued was exacerbated in ground-foragers because snowfall could limit access to ground-borne resources, resulting in food shortages. In comparison, tree-foraging species have more predictable resources, and as such do not need to build up as large a fat supply (Rogers 1987; Rogers and Smith 1993; Graedel and Loveland 1995). The body mass of tree-feeding species varies diurnally and seasonally, although the role of adaptive winter fattening is less prominent (Dawson and Marsh 1986; Silverin *et al.* 1989; Koivula *et al.* 1995; Cooper 2007).

There are several challenges associated with measuring size-corrected body mass in a non-destructive manner, such that ecologists have created various “condition indices” (Sears 1988; Redfern *et al.* 2000; Stevenson and Woods 2006; Jacobs *et al.* 2012). Some of the first indices involved using the ratio of body mass to a metric of body size, such as wing length. However, that method is often inaccurate because body size is seldom directly proportional to body mass (Peig and Green 2009). Calculating residuals from ordinary least squares regression (OLS) is one of the most popular methods, although several have argued that OLS violates key assumptions, leading to Type I and Type II errors (Garcia-Berthou 2001; Green 2001; Peig and Green 2009, 2010). To counter the flaws in OLS, Peig and Green (2009) developed the scaled mass index (SMI), which accounts for covariation between body size and body mass components during calculations by correcting body mass by a relative measure of body length.

Black-capped Chickadees are generally a well-studied species, particularly for food-storing behaviours (Sherry and Vaccarino 1989; Hitchcock and Sherry 1990; Smulders *et al.* 2004), social behaviour (Otter *et al.* 1998; Mennill *et al.* 2003), and vocal communication (Otter *et al.* 1997; Christie *et al.* 2004; Mennill and Ratcliffe 2004). The overall aim of our research was to provide additional information on fat mass variation at short- and long-time scales in Black-capped Chickadees using a 12-year data set and build on previous work that had focussed primarily on changes in muscle mass throughout the year (Swanson and Olmstead 1999; Swanson and Liknes 2006; Petit and Vézina 2014). Although we have direct estimates of visual lipid deposits within our dataset, those visual estimates are subjective and likely influenced by observer bias. Consequently, we elected to use a size-corrected mass index to estimate lipid levels in chickadees, with fat being the major cause of variation in body mass mediating a trade-off between higher reserves (longer fasting duration) and lower load (quicker predator escape). Thus, our first goal was to identify which condition index (body mass only, body mass/wing length, OLS, and SMI), is the most accurate predictor of lipids (as estimated by fat scores) in wild Black-capped Chickadees. We predicted that SMI would be the most reli-

able predictor of fat scores, as SMI accounts for proportions relative to the individual and overcomes the flaws found in OLS. Our second goal was to determine the trends in size-corrected body mass using the available data, through the comparison of the most reliable condition index with various predictors, including mean temperature, time of day, and age. As chickadees are an overwintering species, we predicted that at longer time-scales (months) they undergo adaptive winter fattening. Specifically, we predicted that chickadees would have a higher relative body mass in winter and lower relative body mass in summer. We also predicted that at shorter time scales (hours) chickadees would be lightest in the morning after a night of fasting and would increase in relative body mass through the day due to foraging (Bednekoff and Krebs 1995; Cresswell 1998; Kullberg 1998). Lastly, we predicted that older chickadees, which are more experienced at finding food, and typically of higher rank with better access to food, would need smaller fat reserves (Daunt *et al.* 2007; Marchetti and Price 2008).

Methods

Data were collected in southern Quebec, Canada, at the McGill Bird Observatory from September 2004 until December 2015 as part of banding operations. The bird banding station is located adjacent to the Morgan Arboretum in Sainte-Anne-de-Bellevue, Quebec (45.43°N, 73.94°W), in an open mixed deciduous/coniferous forest. Black-capped Chickadees were caught in a total of 16 mist nets to be weighed, measured, aged, sexed, and banded by trained individuals. Mist nets (110d/2 thread, 30 mm, 4 shelf passerine nests from SpiderTech, Helsinki, Finland) measured 8–12 m in length, 3 m in height, with a mesh size of 30 mm. During the spring and fall migration monitoring period, mist nets were open for five hours daily, starting 30 minutes before dawn except during rain. During the summer, chickadees were captured during MAPS (Monitoring Avian Productivity and Survivorship) operations, with mist nets open for six hours daily, starting 30 minutes before sunrise for each 10-day period (DeSante *et al.* 2016). During the non-standard winter banding, mist nets were employed opportunistically based on the weather conditions. Birds were collected from nets every 30 minutes, or more often during windy days. To reduce the impact on the birds, we did not net in the rain or in very poor conditions, and consequently we may be unable to detect the effect of extreme conditions. Further information about the banding process appears in Gahbauer and Hudson (2014).

The resulting dataset contains 4459 observations from 1866 individuals with outliers (outliers = body weight or wing chord ± 4 SD) removed over the 12-year period. Outliers were likely due to human error during the recording of data. Black-capped Chickadees were aged by variation in their plumage. Not all individuals were reliably aged, depending on the time of

year and the plumage characteristics, and in these cases the birds were recorded as unknowns (Pyle 1997). Chickadees were assigned “young” and “old” age classifications. Birds of unknown age were excluded from the analysis. Fall hatch-year and spring second-year birds were categorized as “young” and fall after hatch-year and spring after second-year were considered “old”, for a total of 4248 observations that were of known age (Table 1). We did not determine the sex of the birds outside of the breeding season, so it was excluded from the analyses. Birds were weighed on an electronic balance (iBalance 700, My Weight Canada, Vancouver, British Columbia, Canada; accuracy of 0.1 g), and wing length was measured with a ruler (accuracy of 1 mm). Each bird was released shortly after the banding process was completed.

Subcutaneous fat was visually estimated using standard protocol and codes from the MAPS program (DeSante *et al.* 2016). As described by Rogers (1991: 351):

Each bird was held in the left hand, ventral side up, with the first two fingers of the left hand on the ventral (first finger) or dorsal (second finger) side of the neck. The first finger pressed against the base of the bill so that the bill pointed forward at approximately 45° above the extended longitudinal axis of the bird. The first finger of the right hand was held lightly against the left side of the pectoral musculature while the right thumb lightly held the tail in its natural position. Birds were held gently to avoid injury, but firmly to avoid escape. With the bird held in the above position, the ventral contour feathers were blown aside and the subcutaneous fat observed in the two defined areas was classified as follows (after Nolan and Ketterson 1983). 0 = no visible fat on abdomen (A) or in furcular depression (F). 1 = F < 33% full, A < 50% covered. 2 = F 33–66% full, A 50–100% covered but fat layer not even with pectoral region. 3 = F filled and fat flush with pectoral musculature, A completely covered, fat layer flush with pectoral musculature, thus neither F nor A bulging outward from pectoral musculature. 4 = as in 3 with F or A bulging. 5 = both F and A bulging. Subcutaneous fat was recognized by its yellow or orange-yellow color, which contrasts with the dark red color of muscle.

Temperature data were collected from the Sainte-Anne-de-Bellevue climate station, located 1.5 km away from the banding sites (45.25°N, 73.55°W), in Sainte-Anne-de-Bellevue, Quebec, Canada. As temperature data were occasionally missing from the local climate station, missing data were replaced using an equation (Sainte-Anne-de-Bellevue Temperature = 0.9987 ×

TABLE 1. Number of captures of Black-capped Chickadees (*Poecile atricapillus*) across a 12-year period in southern Quebec, Canada. Only those used in the analyses are included ($n = 4248$). Seasonal captures across all years were: 332 in late winter (January–March), 297 in spring (April–May), 542 in summer (June–August), 2277 in fall (September–October), and 800 in early winter (November–December).

Year	Number of captures
2015	393
2014	379
2013	272
2012	551
2011	342
2010	711
2009	331
2008	164
2007	307
2006	229
2005	442
2004	127

Airport Temperature – 0.2886, $R^2 = 0.99$) based on available data from the next closest climate station, at the Pierre Elliott Trudeau Airport (16 km away from banding sites; 45.28°N, 73.45°W) in Montréal, Quebec, Canada (Environment Canada 2015).

Comparing condition indices

The regressions of the log-transformed body mass and wing length were taken to determine the slope of the regression (1.105), which was used later during the SMI calculations. We used a linear mixed-effects model (R package nlme; function lme; Pinheiro *et al.* 2016) to compare four different measurement methods: body mass only, body mass/wing length, OLS, and SMI, all of which act as predictors of fat. The data included only the individuals that had been captured at least three times over the duration of the study (2787 observations from 360 individuals) and using a linear mixed-effect model reduced pseudo-replications associated with recaptures. “Body mass only” used the actual weight (g) of each bird recorded by banders. We calculated the “weight/wing length” for each individual by dividing body mass (g) by wing length (mm). We obtained OLS values by calculating the residuals of body mass on wing length using the ordinary least squares regression. SMI was calculated using the formula

$$\widehat{M}_i = M_i \left[\frac{L_o}{L_i} \right]^{b_{SMA}}$$

where slope (1.105) of the body mass ~ wing length regression acted as the scaling exponent, b_{SMA} , and M_i and L_i were the observed values, L_o was the average length value for the entire population, and \widehat{M}_i was the predicted value for mass (Peig and Green 2009). Prior to using parametric statistics, we tested for normality in the data (Shapiro-Wilks; cut-off of $W > 0.95$; R package stats; function shapiro.test; R Core Team 2015).

We excluded fat scores of 4, 5, or 6 due to very small sample sizes, and because the average mass for 4, 5, and 6 were lower than the average fat score of 1, thereby implying they were likely erroneous (i.e., chickadees are never fatter than a 3). The excluded values were distributed randomly throughout the year, and showed no pattern (and were rare), so excluding these values had no impact on our results. Because fat scores do not linearly translate into body mass, we first converted fat into body mass using the same model with fat score as a function of body mass (fixed effect) and individual (random effect), only including those individuals with at least three measurements. Setting a fat score of zero equal to 0 g, based on the linear effects model, a fat score of one was equal to 0.14 g, a fat score of 2 was equal to 0.39 g, and a fat score of 3 was equal to 0.54 g. Next, for each condition index, we calculated a linear mixed-effect model of fat score (converted to mass as above and with fat scores greater than 3 excluded) as a function of condition (fixed effect) and individual (random effect). We used Pearson’s product-moment correlation test (R package stats; function cor; R Core Team 2015) to determine whether wing length is independent of body mass. We used a significance test with alpha set at 0.05 to determine which variables to include in the linear mixed-effect models.

Predictors of variation in size-corrected body mass

We calculated SMI for all 4248 observations for further analyses to test various predictors: temperature, age, and time of capture as time of day, and time of capture in month and years. We corrected for the time of day of capture by sunrise, using the formula: (time of capture – time of sunrise)/day length. Sunrise and day length data were collected from the National Research Council’s sunrise database (National Research Council Canada 2016), using Montréal as the closest available city. Time of capture in month and year for all analyses were treated as categorical variables.

We first explored the relationships between the five possible drivers of SMI individually using univariate tests. For age (old versus young) we ran an unpaired, one-sample t-test (R package stats; function t.test; R Core Team 2015). For temperature and relative time capture we used linear regression (R package lm; function t.test; R Core Team 2015). For month and year of capture we use an analysis of variance (R package aov; function t.test; R Core Team 2015).

Next, we determined the relative strength of each driver, or biologically relevant combination of drivers, using mixed-effect linear models (R package lme4; function lmer; Bates *et al.* 2017), with individual as a random effect. We framed our *a priori* candidate models to test the following hypotheses: (1) including all drivers (temporal, temperature, age) effects additively (global model), (2) average hourly temperature of the capture time alone (temperature model), (3) age of the individual at the time of capture alone (age model), (4) shorter time-scale temporal effects only as capture time of day alone (time of day model), (5) longer time-scale temporal effects including additive effects of month and year of capture (month/year model), (6) longer time-scale temporal effects including additive and interaction effects of month and year of capture (interaction month/year model), (7) short and long time-scale effects together additively (time of day/month/year model), and (8) short and long time-scale effects together additively, and interaction of month and year of capture (interaction day/month/year model). We evaluated all nine models (including a null model with random effect of individual only) using Akaike Information Criterion adjusted for small sample sizes (AICc; Hurvich and Tsai 1989). Models were ranked according to the strength of support of each model, as determined by the difference in AICc between a given candidate model and the model with the lowest AICc ($\Delta AICc$; Anderson *et al.* 2001). AICc is a measure of model performance, which compares the maximum-likelihood estimates of the models, while penalizing for increasing complexity. Ranking was corroborated with the conditional R^2 of the models (R package piecewiseSEM; function sem.model.fits; Lefcheck 2016).

Results

Comparison of condition indices

SMI was the best predictor for subcutaneous fat measured in Black-capped Chickadees ($t_{2423} = 5.05$; $P < 0.0001$), followed by body mass only, body mass/wing length, and OLS (Table 2). Pearson’s product-moment correlation test showed that wing length correlated positively with body mass ($t_{2423} = 43.7$, $P < 0.0001$, $R = 0.55$).

Predictors of SMI in Black-capped Chickadees

We found no significant difference between the SMI of young versus old Black-capped Chickadees (Figure 1a), with older birds having an average SMI of

TABLE 2. Simple regression statistical output for four different body condition indices as predictors of fat in Black-capped Chickadees (*Poecile atricapillus*) captured across a 12-year period in southern Quebec, Canada. Shown are the computed standard error, *t*-value, and *P*-value from a linear mixed effects model.

Model	df	<i>t</i> -value	<i>P</i> -value
Body mass only	2423	4.04	0.0001
Body mass/wing length	2423	−1.67	0.1000
Ordinary least squares regression	2423	1.59	0.1100
Scaled mass index	2423	5.05	<0.0001

10.90 ± 0.62 (SD) g, and young birds having an average of 10.92 ± 0.60 g. While both regressions of temperature and the relative time of capture to SMI were significant ($P < 0.001$), both model fits were low (Adjusted $R^2 = 0.03, 0.005$, respectively; Figure 1). Overall, SMI of Black-capped Chickadees decreased with increasing temperature (Figure 1b) and increased with relative time of capture (Figure 1c). SMI of Black-capped Chickadees also significantly differed across the 12 months of the year, and the 12 years of the study (Figures 1d,e).

Of the nine models tested, the model that included all the temporal variables (time of day of capture, month, and year) explained the most variation in the SMI of Black-capped Chickadees (Table 3). The next best model (month/year of capture, as determined by AICc) was >8 AICc from the top model, thus it was significantly weaker than the top model (Anderson 2008). Thus, SMI variation in Black-capped Chickadees was primarily driven by temporal factors. We found a signif-

icant and positive effect of the time of day, with birds increasing in SMI later in the day (Table 4). Chickadees varied in their SMI across the year, with birds later in the winter (February and March) having significantly greater SMI, and birds in the later summer and fall (July–November) having significantly lower SMI, compared to a January baseline (Table 4). SMI also varied across the 12-years of study, with certain years (e.g., 2013–2015) having chickadees with significantly higher SMI on average (Table 4).

Discussion

SMI as an indicator of fat stores in Black-Capped Chickadees

As predicted, SMI was the most accurate predictor of subcutaneous fat stores in Black-capped Chickadees, followed by body mass only, and body mass/wing length. OLS correlated the least to fat stores. Our results support our prediction that SMI, which corrects body mass by relative wing length, would be the most accu-

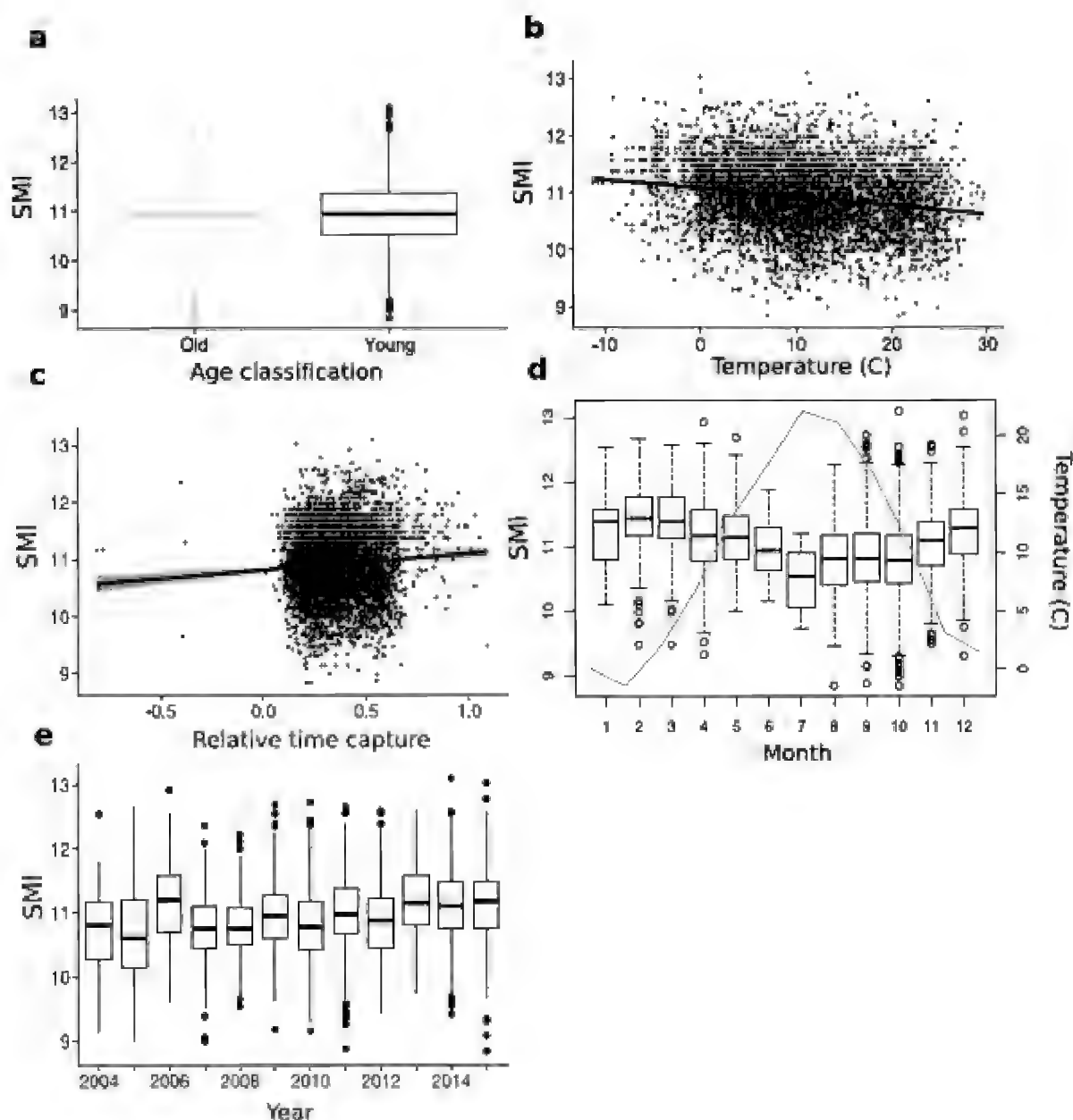


FIGURE 1. a. Boxplot of scaled mass index (SMI) of young and old Black-capped Chickadee (*Poecile atricapillus*); b. scatterplot of SMI versus mean temperature of day of capture for Black-capped Chickadees with linear regression line and 95% confident region in grey; c. scatterplot of SMI versus relative time of capture for Black-capped Chickadee; d. boxplots of SMI of Black-capped Chickadee across 12 months of the year, averaged across all years of study, with line graph of the average monthly temperature for each month across the study period in red; e. boxplots of mean SMI of Black-capped Chickadees across 12 years of the study.

TABLE 3. Summary of rankings of candidate models using Akaike Information Criterion for small sample sizes (AICc) from linear mixed-effects models assessing the variation of scaled mass index (SMI) in Black-capped Chickadees (*Poecile atricapillus*) captured across a 12-year period in southern Quebec, Canada.

Model	df	ΔAICc	Conditional R ²
Time of day/month/year	26	0.0	0.67
Month/year	25	53.9	0.67
Global	113	151.7	0.69
Interaction time of day/month/year	111	182.7	0.69
Interaction month/year	110	232.2	0.68
Temperature	4	509.2	0.61
Time of day	4	577.3	0.62
Age	4	646.2	0.60
Null	3	663.7	0.59

TABLE 4. Parameter estimates from the time of day/month/year linear mixed-effects models assessing the variation of scaled mass index (SMI) in Black-capped Chickadees (*Poecile atricapillus*) captured across a 12-year period in southern Quebec, Canada. Model output for month effects are relative to January, and year effects relative to 2004. Significant parameter estimates are bolded.

Model parameters	Estimates	SE	Df	<i>t</i> -value	<i>P</i> -value
Time of capture	0.36	0.04	3268	7.80	<0.001
Month of capture					
February	0.15	0.07	3423	2.07	0.040
March	0.15	0.06	3397	2.36	0.020
April	−0.03	0.07	3410	−0.49	0.630
May	0.06	0.07	3324	0.84	0.400
June	−0.13	0.11	3763	−1.12	0.260
July	−0.75	0.09	3587	−8.45	<0.001
August	−0.42	0.06	3492	−6.83	<0.001
September	−0.37	0.06	3502	−6.12	<0.001
October	−0.36	0.06	3561	−6.16	<0.001
November	−0.21	0.06	3436	−3.55	<0.001
December	−0.06	0.06	3323	−0.89	0.370
Year of capture					
2005	−0.08	0.05	3930	−1.54	0.120
2006	0.20	0.06	4036	3.10	<0.001
2007	0.02	0.06	4227	0.31	0.760
2008	0.05	0.07	4200	0.67	0.510
2009	0.14	0.06	4218	2.30	0.020
2010	−0.02	0.06	4161	−0.41	0.690
2011	0.13	0.06	4228	2.03	0.040
2012	0.10	0.06	4149	1.72	0.090
2013	0.28	0.07	4202	4.23	<0.001
2014	0.26	0.06	4123	4.05	<0.001
2015	0.18	0.07	4029	2.75	0.010

rate condition index out of the four methods for Black-capped Chickadees. Similar to our findings, SMI was found to be a good predictor in another passerine species, European Starling (*Sturnus vulgaris*; Peig and Green 2009), while being a poor predictor of fat stores in non-passerine birds (Jacobs *et al.* 2012).

The use of OLS as a measure of body condition has been contested in recent years (Labocha and Hayes 2012). Peig and Green (2009) argued that OLS favours large individuals, as OLS measures absolute rather than relative fat (see Blackburn and Gaston 1997). Moreover, OLS may lead to Type I and Type II errors via violations of key assumptions—that the body size indicator (BSI) length (in this study: wing length) is

independent of mass, and that BSI length does not have error (Green 2001). The result from the Pearson’s product-moment correlation test demonstrates that our data violates the first assumption. Conversely, Schulte-Hostedde *et al.* (2005) compared OLS to major axis and reduced major axis regression and found OLS to be the suitable choice. Likewise, Jacobs *et al.* (2012) found that OLS outperformed SMI in predicting lipid stores in seabirds. While “body mass only” was the second most reliable option, we do not recommend using body mass alone as a predictor of fat *in lieu* of other methods, as it is necessary to account for relative proportions of each individual.

Temporal drivers as strongest predictors of SMI variation in Black-Capped Chickadees

Temporal variables at both short time-scales (hours of the day) and long time-scales (months and years), were the strongest predictors of SMI variation in the Black-capped Chickadees in our study area. SMI was lowest in the morning and higher later in the day, which supports our prediction. Black-capped Chickadees spend several hours in the morning foraging to compensate for the energy lost the previous night. As hours go by, mass will increase until nightfall arrives again and body mass drops (Brittingham and Temple 1988). As shown in other studies, plasma triglycerides, indicative of fattening, are also high through mid-morning before dropping off in the afternoon, implying that most fattening occurs in the early morning (Mandin and Vézina 2012; Devost *et al.* 2014). Triglyceride levels, and therefore fattening, are highest in mid-winter (Mandin and Vézina 2012), consistent with our study.

SMI was, averaged across years, lowest from July to November, and highest in January to March suggesting that Black-capped Chickadees undergo adaptive winter fattening, although seasonal variation in body mass may be stress-induced or adaptive in other ways (Ketterson *et al.* 1991; Cresswell 1998; Kitaysky *et al.* 1999; Thomas 2000; Krams *et al.* 2009; Ratikainen and Wright 2013). Lower body mass in summer may be attributed to the stress of breeding season (Nagy *et al.* 2007), or reduction in energetic demands when flying to facilitate delivery of food to nestlings (Freed 1981; Croll *et al.* 1991). However, as we found low SMI from July–November, including the period well outside of the breeding season, we suggest that changes in SMI are mostly associated with winter fattening. Interestingly, we found that mean temperature did not significantly affect SMI in chickadees despite the seasonal variation in body mass. This discrepancy suggests that fat mass is programmed to increase during winter, rather than in response to immediate ambient temperature, although other factors, such as food availability and predation risk, may play important roles. These results are similar to other studies on tree-foraging species, including American Goldfinch (*Spinus tristis*; Dawson and Marsh 1986), Great Tit (*Parus major*; Silverin *et al.* 1989), and Willow Tit (*Poecile montanus*; Silverin *et al.* 1989; Koivula *et al.* 1995).

Age did not significantly affect SMI. In other species, weight generally increases with age due to growth and perhaps an improvement in feeding efficiency (Brooke 1978; Weimerskirch 1992). However, previous work on chickadees has demonstrated that birds of higher rank, which tend to be older (3.2 y compared to 1.5 y for subordinates), are often lighter with lower fat scores, presumably because they have better access to food sources (Schubert *et al.* 2007). We expected younger birds, presumably of lower rank, to have a higher SMI to buffer against the risk of starvation, a threat which

might be greater for younger birds, but our data do not reflect this.

Black-capped Chickadees are often the focus of food-caching research, but there are few data on predictors and mechanisms behind body mass variation in this species. Although chickadees demonstrated winter fattening, it remains to be seen if temperature acts as a proximal or ultimate cause of weight gain/loss. The next step is to undertake experimental manipulations of temperature to determine how that influences avian body mass. Past studies have demonstrated that temperature, when measured over a longer period of time (e.g., several days to a month), acts as a proximal influence on metabolic rate in chickadees (Swanson and Olmstead 1999; Dubois *et al.* 2016). This current study used a much smaller window (time of capture) to assess the impact of temperature, and thus future research may wish to examine longer temporal variables as potential proximate factors.

Author Contributions

Writing – Original Draft: E.N.; Writing – Review & Editing: K.E. and B.F.; Data Collection: B.F.; Formal Analysis: E.N., B.F., and K.E.

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Note

New size record for Snapping Turtle (*Chelydra serpentina*) in southern Quebec, Canada

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Abstract

We report a new size record for a Snapping Turtle (*Chelydra serpentina*) in Quebec, Canada. We captured an adult male in good general condition in the Rivière du Sud in the southern Montérégie region. Its straight midline carapace length was 43.2 cm (maximum carapace length 45.1 cm), and it weighed 19.8 kg. This record contributes to our understanding of the maximum size of this species at the northeastern part of its range. More intensive effort will be necessary to document the Snapping Turtle population structure in Quebec to allow for sound comparisons with other populations, as well as a better understanding of the effects of elevation, latitude, and local habitat on Snapping Turtle growth and size.

Key words: Snapping Turtle; *Chelydra serpentina*; size record; Rivière du Sud; northeastern range; Quebec; Canada

Résumé

Nous rapportons un nouveau record de taille pour une tortue serpentine (*Chelydra serpentina*) au Québec, Canada. Nous avons capturé un mâle adulte en bonne condition générale dans la rivière du Sud dans le sud de la Montérégie. La longueur standard de la carapace était de 43,2 cm (longueur maximale de la carapace 45,1 cm) et il pesait 19,8 kg. Ce record contribue à une meilleure connaissance sur les tailles maximales de l'espèce dans le nord-est de son aire de répartition. Des efforts plus importants seront nécessaires pour documenter la structure de population de la tortue serpentine au Québec afin de permettre des comparaisons fiables avec d'autres populations, ainsi qu'une meilleure compréhension des effets de l'altitude, de la latitude et de l'habitat local sur la croissance et la taille de la tortue serpentine.

Mots-clés: tortue serpentine; *Chelydra serpentina*; record de taille; rivière du Sud; nord-est de l'aire de répartition; Québec; Canada

Finding the largest individuals of a turtle species in a given region requires perseverance and good data collection methods. Since 1992, we have been conducting research and managing an observation network to gather information related to herpetofauna distribution, reproduction, road mortality, and abnormal colouration and morphology among other topics. Observations from the public often consist of female turtles seen crossing a road or digging a nest in a garden during nesting season or turtles captured accidentally during sport fishing (Galois and Ouellet 2007a,b; Amphibia-Nature Observation Network unpubl. data). Reported size is usually a visual approximation, especially when the subject is an impressive Snapping Turtle (*Chelydra serpentina*). Despite the limited number of this species, occasional captures made during our biodiversity projects provide reliable and precise data. Here, we report the largest Snapping Turtle documented in Quebec, Canada.

The observation was made during a biodiversity survey in the Rivière du Sud, a tributary of the Rivière Richelieu, in Quebec's southern Montérégie region. After capturing the Snapping Turtle from a boat using a dip net, we examined it for general condition, measured

it, and documented the observation using digital photography.

We used a forestry caliper (Dendrotik, Quebec, Canada) to measure to the nearest millimetre the straight midline carapace length (CL_{mid}), maximum carapace length (CL_{max}), maximum shell width (SW), straight midline plastron length (PL_{mid}), posterior lobe length of the plastron (middle scales suture of the plastron to the posterior end), precloacal length (posterior end of the plastron to the centre of the cloaca), and posterior end of the plastron to the tail extremity. To weigh the turtle, we used a 22.0-kg spring scale (Matzuo America, Illinois, USA) with 0.2-kg gradation. We released the turtle at the point of capture immediately after the measurements were made.

We searched the literature to obtain published information on Snapping Turtle size in North America. We also checked our own database for information we collected in the field and obtained through our observation network (<https://www.amphibia-nature.org>).

We captured the adult male Snapping Turtle on 3 July 2016 in the Rivière du Sud, Quebec (45°05'N, 73°13'W; datum WGS84). At the capture location, the river was characterized by slow moving water and shallow river-

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ine marsh, with the navigable open section limited to a narrow channel (Figure 1). The turtle was lying in shallow water on a muddy substrate. As we approached at reduced speed, the turtle started to move slowly beside the boat, allowing capture.

The turtle's dimensions were: CL_{mid} 43.2 cm (Figure 2), CL_{max} 45.1 cm, SW 36.0 cm, and PL_{mid} 30.2 cm. The distance between the posterior end of the plastron and the tail extremity was 42.4 cm. Total weight was 19.8 kg. With a morphological ratio of precloacal length (17.8 cm) to plastron posterior lobe length (12.8 cm) of 1.39, the turtle was determined to be male (Ernst and Lovich 2009; Dustman 2013). The turtle was in good general condition with no apparent injuries. Five leeches (*Placobdella parasitica*) were present on the carapace.

To our knowledge, the carapace length of this Snapping Turtle is the longest measured and reported in Quebec. In June 1939, a large turtle was captured on a road near Van Bruyssel, a hamlet in the Mauricie region, and brought to the Jardin zoologique de Québec (Bernard 1948). Reported measurements were: CL 18 inches (45.7 cm) and weight 30 pounds (13.6 kg). Unfortunately, it was not specified whether the carapace measurement was taken as a straight line or along the carapace curvature, and no picture was provided. Moreover, the weight of this turtle was abnormally low in

relation to the carapace length based on data from other studies (Lagler and Applegate 1943; Hammer 1969; Johnston *et al.* 2012); therefore, the measurements are considered questionable. Two other well documented large male Snapping Turtles found in Quebec each had a CL_{max} of 43.0 cm (Desroches 2007), 2.1 cm shorter than our record. One of these was found dead in 2003 in the same area as our observation in the Rivière du Sud.

Large male Snapping Turtles have been reported in the literature from various locations in North America. Snapping Turtle males grow larger than females, and female size tends to increase with increasing latitude and elevation (Moll and Iverson 2008). In Minnesota, at 47°37'N, further north than our observation area, a male Snapping Turtle had a CL of 49.4 cm (not specified whether straight midline or maximum; Gerholdt and Oldfield 1987). In comparison with our observation, this conforms to the latitude trend of larger individuals in the north. However, in Ontario's Algonquin Park, a latitude (45°35'N) close to that of our area, the largest male captured had a CL_{mid} of 39.5 cm (Obbard 1977), i.e., smaller than our record. In Massachusetts (Middlesex County centroid 42°28'N), a male turtle's unspecified CL was 50.7 cm (Hunter *et al.* 1992), and, in Nebraska (41°44'N), the largest individual captured in Island Lake had an unspecified CL of 46.4 cm (Iver-



FIGURE 1. Adult Snapping Turtle (*Chelydra serpentina*) captured in the Rivière du Sud in southern Quebec, Canada. Photo: È.-L. Grenier.



FIGURE 2. The observed Snapping Turtle (*Chelydra serpentina*) was a male with a straight midline carapace length of 43.2 cm and a maximum carapace length of 45.1 cm. Photo: P. Galois.

son *et al.* 1997). The largest males in Florida populations in the Santa Fe River (29°52'N) and in Wekiwa Springs State Park (28°43'N) had CL_{max} of 45.0 cm (Johnston *et al.* 2012) and 44.8 cm (Walde *et al.* 2016), respectively. These measurements are only a few millimetres smaller than our record, but they are also smaller than some CL_{max} reported in other northern latitudes (Gerholdt and Oldfield 1987; Hunter *et al.* 1992).

Thus, these size records for male Snapping Turtles do not support the suggested relation between latitude and maximum size. The same discrepancies can also be found for females. A large female (CL_{mid} 37.3 cm, CL_{max} 39.9 cm) was found dead in Parc National des Îles-de-Boucherville (45°36'N) near Montréal, Quebec (Desroches 2007). In 2015, we captured a female with CL_{mid} 37.0 cm in Parc-nature du Bois-de-l'Île-Bizard (45°30'N) near Montréal, Quebec (P.G. and M.O. unpubl. data). A large female with CL_{mid} 35.8 cm was captured in Algonquin Park (Obbard 1977), and a female with unspecified CL 38.4 cm was captured in South Dakota (43°09'N; Hammer 1969). The largest female in a Florida population had a CL_{mid} of 38.0 cm (Johnston *et al.* 2012), close or even larger than female CL_{mid} reported in some northern populations. Thus, the relation between latitude and both male and female Snapping Turtle size needs further investigation.

Although size records are of interest, they remain anecdotal until ample data are collected to verify whether these large individuals are exceptional or relatively common in their populations. More intensive effort is necessary to document Snapping Turtle sizes and population structure in Quebec, at the northeastern limit of the species range, to allow more useful comparisons with other northern and southern populations. These studies would allow for a better understanding of the effects of elevation, latitude, and local habitat on Snapping Turtle growth and size. They would also provide data relevant to investigations of the effect of climate change on Snapping Turtle population structure over time.

A climate warming trend at northern latitudes could favour an extension of the species range toward the northeast by providing a long enough period for successful egg incubation. We already know that Snapping Turtle reproduction occurs as far north as 48°19'N in Abitibi, western Quebec (Lapointe 2018). In Canada, Snapping Turtle observations range northward to 51°N in western Ontario and 52°N in Manitoba (COSEWIC 2008). Therefore, additional information on Snapping Turtle distribution and population structure at northern latitudes is particularly important to allow for the documentation of potential changes over time in response to climate change. Our turtle observation network is an

effective tool to obtain information from remote locations. Details, including date and location, and photos can be submitted online (<https://www.amphibia-nature.org>) or sent to info@amphibia-nature.org. With or without measurements, this information might help in identifying sites where more intensive surveys could eventually be undertaken to improve knowledge of Snapping Turtle populations at the northern limit of their range.

Author Contributions

Field work, Writing – Review & Editing: P.G., È.-L.G, and M.O.

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Predation on Caribou (*Rangifer tarandus*) by Wolverines (*Gulo gulo*) after long pursuits

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Abstract

Ungulates are an important source of food for Wolverines (*Gulo gulo*), especially in winter when scavenging on carcasses is a primary means of obtaining food. However, Wolverines are also known to prey on ungulates. We followed fresh tracks of Wolverines pursuing Caribou (*Rangifer tarandus*) on six occasions on the tundra of northern Alaska in 2011, 2015, 2017, and 2018; all ended in a predation event after pursuits of 4–62 km. Exhaustion of the Caribou after long pursuits appeared to contribute to the success of predation attempts. Snow conditions appeared to be a factor in only one of the six cases.

Key words: Alaska; Caribou; *Gulo gulo*; predation; *Rangifer tarandus*; Wolverine

Introduction

Ungulates are an important source of food for Wolverines (*Gulo gulo*), especially in winter when scavenging on carcasses is a primary means of obtaining food (Banci 1994; Copeland and Whitman 2003). However, Wolverines are capable of killing ungulates, including Moose (*Alces americanus*; Haglund 1974), Caribou/Reindeer (*Rangifer tarandus*; Burkholder 1962; Lofroth *et al.* 2007; Mattisson *et al.* 2017), Mountain Goats (*Oreamnos americanus*; Lofroth *et al.* 2007), Dall's Sheep (*Ovis dalli*; Gill 1978), and Elk (*Cervus canadensis*; Inman and Packila 2015). In Scandinavia, Wolverines are one of the main predators of unattended, free-ranging, semi-domestic Reindeer. While tracking Wolverines in snow and locating Reindeer carcasses fed on by Wolverines, both Haglund (1966) and Bjärvall (1982) stated that Wolverines were responsible for killing at least 30% of the Reindeer at the carcass sites they found. Mattisson *et al.* (2017) reported average individual kill rates for Wolverines ranging from less than one to five Reindeer per month depending on season and area, with as many as 15 during a single month.

Predation on ungulates by Wolverines is thought to occur opportunistically, with vulnerability of prey being a key factor determining the success of predation attempts (Haglund 1966; Banci 1994; Mattisson *et al.* 2017). Factors affecting vulnerability of prey include deep or crusted snow (Haglund 1966; Bjärvall 1982), poor body condition (Lofroth *et al.* 2007; Mattisson *et al.* 2017), and age of prey (Gustine *et al.* 2006; Inman and Packila 2015; Mattisson *et al.* 2017).

We are not aware of published reports of Wolverines pursuing Caribou over long distances in predation attempts. Haglund (1966) stated that no pursuits of Reindeer by Wolverines were more than 1 km. However, Reindeer herders and field personnel of the Norwegian Environment Agency in Scandinavia have reported long chases by Wolverines (J. Mattisson pers. comm. 9 January 2018). Here we report six occurrences of Wolverines killing Caribou after pursuits of 4–62 km on snow-covered tundra in northern Alaska.

Methods

We documented Wolverines killing Caribou by following Wolverine and Caribou tracks from a PA-18 Super Cub aircraft (Piper Aircraft, Vero Beach, Florida, USA). We made opportunistic observations on the Alaska North Slope between 68°N and 70°N and between 147°W and 155°W, while primarily engaged in Wolverine surveys and, in one case, during a Caribou telemetry flight. Poley *et al.* (2018) have presented details of the Wolverine survey methods.

Habitat in the study area consisted of snow-covered tundra with gentle relief, small drainages with shrubs protruding above the snow, and occasional ridges blown free of snow. Except for observation 4 below, snow conditions were similar throughout the track sequences and consisted of relatively firm, windblown snow, in which Wolverine tracks penetrated 0.5–10.0 cm and Caribou tracks perhaps slightly more, depending on conditions.

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Observations

(arranged chronologically within year from most recent year)

Kill 1

On 8 April 2018, while conducting a survey for Wolverine tracks in the Arctic National Wildlife Refuge in northern Alaska, P.V. and A.J.M. came across the tracks of a Wolverine and a Caribou that led to a Caribou carcass, near which a Wolverine was seen running at the approach of the aircraft. The Caribou kill was very fresh with the head only partly removed by the Wolverine. The Caribou had hard antlers, indicating it was a pregnant cow. The tracking team back-tracked the pair of footprints for 18 km before returning to the carcass where the Wolverine had just finishing removing the head.

At about the same time, M.A.K. and C.R.L. were tracking a Wolverine and Caribou ~50 km away (straight-line), where a Wolverine had encountered a small herd of Caribou and began pursuing one of them. They tracked the animals for 20 km to where the tracks disappeared in a windblown area. At that point, they returned to their survey route but, later that day, picked up the back-tracking effort from where the first team had stopped and followed the Wolverine and Caribou for an additional 22 km to within 2 km of where their forward-tracking session had ended earlier in the day, and the tracks again disappeared in the windblown area.

Piecing together the tracking sessions, the teams calculated that the total distance of the Wolverine's pursuit of the Caribou was 62 km. For most of the track sequence, the Wolverine tracks were a typical three by three pattern with spacing that indicated a fast and steady lope but not a full run, closely following the route of the Caribou. There were shorter sections of tracks where patterns indicated increases or decreases in speed, perhaps associated with changes in slope, snow conditions, or distance between the animals. There were occasional divergences between the two sets of tracks where the Wolverine took a more direct line to try to intersect the Caribou. The Caribou tracks indicated a similar strategy of an overall fast pace but not a full run, except near the end of the pursuit when both the Wolverine and Caribou appeared to run full speed. Along the chase route and at the kill site, there were no tracks of Wolves (*Canis lupus*), the only other Caribou predator in the study area in winter.

Kill 2

On 3 April 2017, M.A.K. and C.R.L. came across Wolverine tracks following the trail of a single Caribou and tracked the animals for 31 km to a freshly killed Caribou with the Wolverine resting next to the carcass. We estimated that the Caribou had been killed within an hour before our arrival based on the freshness of blood in the snow and the lack of feeding or caching activity by the Wolverine. We also returned to the point where

we first found the tracks and traced them 4 km back to the point where the Wolverine started following the Caribou. The entire distance travelled by the Caribou and Wolverine was ~35 km, and the tracks roughly formed a large loop.

There was no indication that the Caribou floundered in snow while the Wolverine travelled on the snow surface. Throughout the track sequence, we did not observe anything to indicate that the Caribou or Wolverine tried to take advantage of any particular snow type or topographic feature (e.g., staying on the crest of a ridge where snow was hardest or following tracks from other groups of Caribou). Based on the tracks, covering distance seemed to be the strategy of the Caribou. With the exception of the last 100 m, there appeared to be no direct interactions between the Caribou and Wolverine (i.e., the Wolverine did not try to jump on or attack the Caribou during the pursuit). We suspect that the Wolverine simply followed closely behind the Caribou, eventually exhausting it. In the last 100 m, tracks showed that the Wolverine attempted to jump on the Caribou several times. Tracks at the kill site indicated relatively little struggle. No other predator tracks were observed during the tracking session.

Kill 3

On 5 April 2017, M.A.K. and C.R.L. found Wolverine tracks along with the tracks of two Caribou and tracked the animals for 31 km to the kill location. The Wolverine was not in sight when we arrived. Pursuit behaviour was similar to that in kill 2. We estimated that the Caribou had been killed approximately two days earlier based on the age of snow, the freshness and amount of blood in the snow, the nearly complete caching of the carcass in the vicinity of the kill site, and the amount of tracking at the kill site. We did not return to where we initially intersected the tracks to back-track to the beginning of the pursuit, so the entire length of the pursuit is unknown.

In this track sequence, the Caribou and Wolverine generally stayed on the crest of a ridge, where perhaps snow conditions were firmer than in the valley bottoms. As with kills 1 and 2, the Caribou did not flounder in snow or break through crust into deep snow. Except in the last 400 m, there appeared to be no direct interactions between the two Caribou and the Wolverine. Starting ~400 m from the kill site, both the Caribou and the Wolverine made a loop of about 100 m, at which time the two Caribou separated. The Caribou that was still being pursued by the Wolverine then travelled a short distance before making several rough figure eights ~100 m long before the Wolverine caught and killed it. The site of the kill did not indicate a long struggle between the Caribou and Wolverine once the Wolverine had overtaken the Caribou. The second Caribou was not pursued by the Wolverine once it separated from the other. We observed no Wolf tracks at the kill site or along the chase route.

Kill 4

On 9 April 2017, while searching for fresh Wolverine tracks, P.V. and A.J.M. saw a Wolverine sitting beside a Caribou carcass with fresh blood in the snow. We back-tracked the Wolverine and Caribou tracks to determine how the kill was made. The Wolverine had apparently spotted a group of about eight Caribou feeding on the bank of a large lake and ran toward them. The Caribou ran down onto the wind-hardened, snow-covered lake, where both the Wolverine and Caribou were able to stay on top of the snow. The Caribou ran across the lake and started up the bank on the far side, at which point they broke through the snow crust covering shrubs bordering the lake. Before the Caribou reached the hard-packed snow at the top of the bank, a 10-month-old calf veered from the group and was quickly subdued by the Wolverine. The entire chase sequence covered 4 km. We landed the ski plane on the frozen lake and walked to the kill site. The Wolverine had eaten off the nose of the calf and had chewed into the throat and back of the head. No other wounds were evident and the calf was not yet fully frozen. We observed no wolf tracks in the area.

Kill 5

On 25 March 2015, M.A.K. and C.R.L. found the tracks of a Wolverine and a Caribou, which appeared to be less than 24 h old, and followed them for 9 km to where the Wolverine had killed the Caribou and apparently cached parts of it nearby. We saw the Wolverine as it ran from the kill site on our approach. We did not back-track to determine the total length of the pursuit. Track patterns of the pursuit were similar to those of kills 2 and 3. The only other tracks in the area were of Red Fox (*Vulpes vulpes*).

Kill 6

On 7 April 2011, L.S.P. encountered the tracks of a Wolverine following the trail of a Caribou and followed the tracks for ~26 km, mostly along a creek bottom. We did not back-track to determine the total length of the pursuit. There was no evidence of interaction along the route. We could not tell whether the Caribou knew the Wolverine was following it. Eventually, the Caribou climbed a hill overlooking the creek and bedded down on a slope. The tracks indicated that the Wolverine approached the hill outside the view of the Caribou, came over the crest, bounded a short distance to the Caribou, and then both animals apparently rolled together to the bottom of the hill. The Wolverine had just begun dismembering the carcass when we arrived at the site.

Discussion

In these accounts, the vulnerability of the Caribou to predation was only evident in kill 4 (i.e., crusted snow that broke under the weight of the Caribou). In the other five cases, lack of evidence of extended struggles at the kill sites suggests that exhaustion of the Caribou ended the pursuit. Both Wolverines (Haglund 1966; Bjärvall

1982) and Caribou (Pritchard *et al.* 2014) are capable of sustained, long-distance movements, but physical endurance will determine the outcome of long pursuits when movement rates are rapid. During 1-h continuous observations of Wolverines travelling (but not pursuing prey at maximum speed), Magoun (1985) documented speeds of up to 8.0 km/h for female Wolverines and up to 10.6 km/h for males in summer on tundra. If we consider 8–10 km/h to be the maximum sustained speed for Wolverines on firm snow in winter, the long pursuit in kill 1 could have lasted ≥ 6 h.

Pritchard *et al.* (2014) documented a maximum movement rate for a Caribou in our study area of 13.8 km/h (straight line winter movement of a female wearing a GPS collar with a 2-h fix interval), but this rate of movement was rare in their study. If sustained for 62 km, a pursuit at this speed would have lasted 4.5 h. Although the speeds of Wolverines and Caribou seem well-matched, the persistence of the Wolverines was likely key to predation success in the long pursuits we documented.

We did not determine the frequency of successful predation attempts. We only followed very fresh tracks when we were reasonably confident that we could find the Wolverine, and long pursuits had a better chance of being detected by us during our survey flights. Also, we cannot conclude that longer pursuits result in more successful predation attempts or that all pursuits under similar winter conditions are as successful as those we observed.

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Note

Swimming as a potentially important emergency capability of White-throated Swifts (*Aeronautes saxatalis*) engaged in aerial mating

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Abstract

It seems reasonable that birds that court or mate in the air over lakes or rivers should be capable of taking off from water or be able to swim, as they might find themselves in the water as a result of this activity. Nonetheless, interaction with water has rarely been documented in the wild and has not been reported for any species of swift in Canada. I report an incident of such activity, however, from Oliver, British Columbia. In this case, I observed a White-throated Swift (*Aeronautes saxatalis*) swimming vigorously for over 10 minutes before reaching dry land approximately 85 m away. The bird likely fell into the water as a result of flight miscalculations during aerial courtship or mating. I speculate that its swimming capability was aided by the long, narrow, flipper-like wings of the species. I did not observe the bird take flight from the water surface. From these observations, it is evident that White-throated Swifts are relatively strong, capable swimmers, at least for short periods.

Key words: White-throated Swift; *Aeronautes saxatalis*; swimming; aerial mating; British Columbia

McGuire and Brigham (2017) reported seeing Common Nighthawks (*Chordeiles minor*) taking wing immediately after rare incidents of the birds hitting the surface of a water body. The recovery flight was immediate in one case and somewhat delayed in the other, occurring after several seconds of the bird drifting (not swimming) on the surface. Jackson (1970) reports almost identical behaviour of a Barn Swallow (*Hirundo rustica*) immediately following its release from banding. McGuire and Brigham (2017) logically imply that a capacity for swimming is important for species that are active over water, especially those twisting and turning rapidly in their aerial pursuit of insect prey. In the case of Common Nighthawk, such activity would also be undertaken in poor light conditions. Individuals unable to respond successfully to occasional “ditchings” likely have a higher probability of mortality.

McGuire and Brigham (2017) document a number of other passerine bird species capable of taking off from water and/or swimming for short distances. They further note that, although several swallow species have been observed swimming, observations are lacking for other aerial insectivores, such as swifts. Indeed, they cite Lowther and Collins (2002) as stating that Black Swifts (*Cypseloides niger*) do not swim, although no particular evidence or qualifications of that statement are offered. McGuire and Brigham (2017: 126) go on to conclude: “there are no reports [of swimming] for other swifts found in Canada”. The following provides documentation of such behaviour by a swift in Canada. This report is based on field notes made by the author at the time of the original observations.

White-throated Swift (*Aeronautes saxatalis*) is found in Canada only in southern British Columbia where it

builds nests in large colonies in crevices of high bedrock cliffs or on conglomerate bluffs (Godfrey 1986). Some of the colonies in the Okanagan Valley are situated over water. Aerial courtship and mating activity at and about the nesting colony require swifts to spend considerable time in extraordinarily complicated and seemingly perilous flight over water. This aerial mating behaviour was beautifully described at a breeding colony over Vaseux Lake in the Okanagan Valley in May 1922:

[T]hey copulate in the air. At least several times I saw two meet, apparently face to face high in the air, cling together as though embracing for a moment through which they drop down hundreds of feet, there to separate and catch themselves on their wings (Percy A. Taverner, as cited by Cannings *et al.* 1987).

On 10 June 1982, I and several others witnessed an apparent malfunction of this aerial mastery at a large White-throated Swift breeding colony 6 km north of Oliver, Okanagan Valley, British Columbia (49.2413°N, 119.5182°W). This is only a few kilometres south of Taverner’s observations of 60 years earlier. The 250-m tall, west-facing nesting cliff here towers over Gallagher Lake, a small (5.3 ha) pond situated in semi-arid Ponderosa Pine (*Pinus ponderosa* Douglas ex Lawson & C. Lawson) forest (Figure 1). Numerous individual swifts as well as pairs were observed performing spectacular aerial feats over a 2-h period before sunset. At least 50 instances of pairs involved in “courtship falls” (Ryan and Collins 2000) were noted during that time. Much as described by Taverner (above), these courtship falls involved pairs of birds tumbling through the air for 150–200 m and then veering off from seemingly cer-

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tain contact with the lake surface. It was not possible to measure how close to the water surface the birds came but it appeared to be less than a metre. Remarkably, no contact with the water was witnessed in any of these displays.

Near sunset at 2100, we observed a bird floating and flapping in the middle of the lake ~150 m away (Figure 1). None of us in a group of six observers (all birders) had noticed it hit the water. Observation through a 30–60× zoom spotting scope confirmed that it was an adult White-throated Swift (sex undetermined); no juveniles are present at this date, well before nestling hatching in the Okanagan Valley (Cannings *et al.* 1987). Observation conditions were excellent on this calm, warm, clear evening and our consensus was that a bird flapping on the still water could not have avoided detection for more than about five minutes.

Over the following 10 minutes we observed the swift through the spotting scope as it swam toward the shore of the lake ~85 m away. It did this by rapidly stroking both wings in unison, with a brief (~1 s) pause between strokes. After a series of 10–20 such quick strokes, it floated quietly for 5–10 s, then proceeded to swim further. The bird was quite buoyant and held its head distinctly above the water throughout, both during active swimming as well as during the brief pauses.

At one point, it attempted to climb onto a swim raft anchored near the lakeshore (Figure 1), but could not scale the ~40 cm vertical sides of the raft. The bird abandoned that effort after a minute or two of unsuccessful scrambling and resumed its open-water swimming. When the bird reached the lakeshore and crawled onto a stranded log, it was trembling strongly and appeared exhausted. It made no attempt to fly and offered no resistance when approached and picked up by one of our group of observers. It was clear-eyed, alert, and silent. After two minutes the trembling stopped but the bird remained placidly perched in hand, with its toes wrapped firmly around the finger of the observer. Although its body feathers were wet (soaked virtually to the skin), its head was completely dry.

The bird remained quiet and completely inactive over the next 45 minutes as it began to dry off. It did not attempt to preen or aid in drying its feathers. As it was now almost completely dark, we placed the bird on dry towels in a cardboard box covered lightly by a cloth and left it in a quiet corner of a residential room overnight. The box was taken outside the following morning about 0700 (10 h later) and uncovered. The bird made no attempt to fly from the box. It was picked up (again offering no resistance), held up toward the open sky and released from the hand. It flew directly

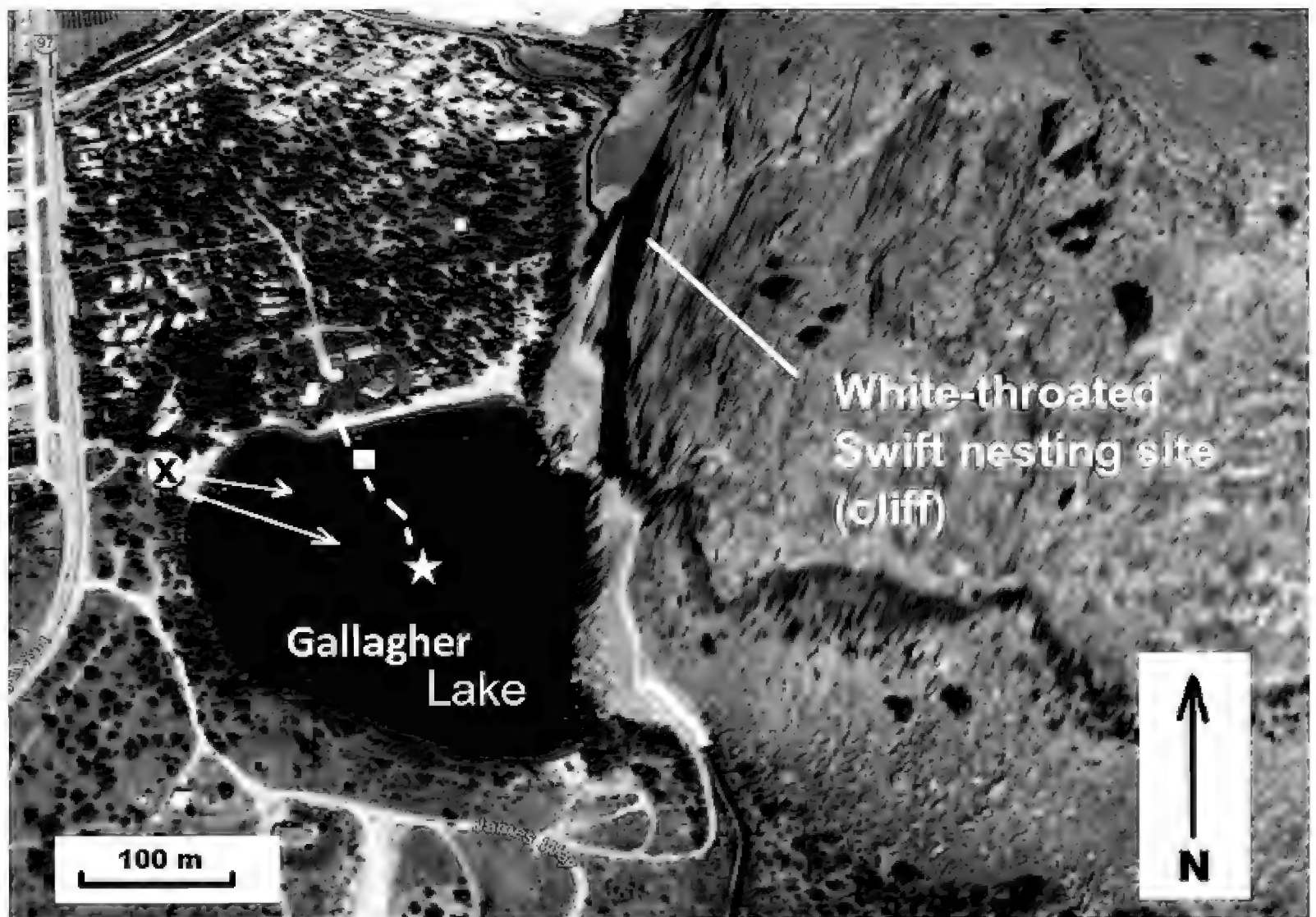


FIGURE 1. Location of observations of a swimming White-throated Swift (*Aeronautes saxaltis*), Gallagher Lake, British Columbia. X and arrows = observers' position and viewpoints; star = first noted location of swift on the water; dash line = approximate route of swim; square = approximate location of swim raft. Base image: GoogleEarth, 25 August 2016.

and strongly across the pond and back to the nesting cliff.

Given their propensity for high-speed acrobatic flying while over water bodies, it is not surprising that White-throated Swifts might, at least occasionally, hit the surface of the water. That such impacts occur, at least rarely, is also implied by historical references to White-throated Swifts striking the ground during courtship fall behaviour. Shufeldt (1887) describes two such entangled birds in New Mexico hitting the ground in a cloud of dust and, after several seconds, flying off separately. More dramatically, Van Tyne and Sutton (1937: 42) reported that White-throated Swifts at Emory Peak in western Texas “were often seen mating, and fierce aerial battles (between rival males?) sometimes persisted until the combatants struck the talus slope below and rolled down the steep declivity, still locked in bitter struggle”. They do not state whether the “combatants” were able to fly off after such groundings.

Less foreseeable than the occasional occurrence of water ditchings was the fact that the Gallagher Lake swift could swim so adeptly for about 85 m and stay afloat for a considerable time. It had no evident difficulty maintaining a head-high profile throughout its swim. McGuire and Brigham (2017) noted that the Common Nighthawks they observed to land accidentally on a water surface also appeared buoyant. That ability would presumably reduce energy requirements and improve the bird’s chances of a successful landfall (in the case of a swift) or flight from the surface (with the nighthawks). In comparison to the broader wings of most passerine species, the long, narrow, flipper-like wings of White-throated Swift also may assist in swimming efficiency and reduce the energy demands of that activity.

The Gallagher Lake bird showed no outward signs of injury from its ordeal and was seemingly able to recover its pre-ditching vigour within 10 h. It did not experience the feather loss from physical contact that McGuire and Brigham (2017) observed in Common Nighthawks with wet plumage. No loose feathers were noted in the box in which the swift was confined overnight.

Unlike Shufeldt’s (1887) report of White-throated Swifts being able to rise from the ground, I saw no evidence that the Gallagher Lake bird was capable of flying directly from the surface of the water. Its inability to surmount the short vertical wall of the swim platform

despite expending substantial effort in the attempt, suggests that its lift capacity had been reduced by the wetting of its plumage. These observations demonstrate, however, that, at least under emergency conditions, White-throated Swifts do have the advantageous ability to swim for a considerable distance.

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Note

Round-fruited St. John's-wort (*Hypericum sphaerocarpum*, Hypericaceae) in Canada

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Abstract

Round-fruited St. John's-wort (*Hypericum sphaerocarpum*), a native North American herbaceous, perennial vascular plant, is reported from four sites in southern Ontario, Canada. All four sites are along abandoned railway lines. Although the rich association of native flora suggests native status at one site, *H. sphaerocarpum* is believed to be introduced elsewhere in its Canadian range in Ontario.

Key words: Round-fruited St. John's-wort; *Hypericum sphaerocarpum*; Hypericaceae; Ontario; Canada; range extension; railway

Round-fruited St. John's-wort (*Hypericum sphaerocarpum* Michaux) is native to the midwestern and southern United States from Oklahoma east to southeastern Ohio and from southern Wisconsin south to Mississippi and Alabama (Robson 1996, 2015). Here, we report four records of *H. sphaerocarpum* from southern Ontario, Canada (Figure 1; see “Voucher specimens” below), representing a northeastern extension of the species' range. *Hypericum sphaerocarpum* is not listed for Canada by Scoggan (1978–1979) or Gillett and Robson (1981), and its inclusion in later publications, e.g., Morton and Venn (1990), Newmaster *et al.* (1998), and Robson (2015), is based on the records reported here.

Hypericum sphaerocarpum can be distinguished from other Ontario *Hypericum* species by the combination of its being herbaceous, 10–30 cm tall, having pinnately veined leaves 3.5–7 cm long, flowers <3 cm broad with more than 20 stamens and lacking black spots or streaks on the petals, and styles joined to form a beaked fruit (Robson 1996, 2015).

It was first discovered in Ontario and Canada on 19 September 1983 by M.J.O. along the then-active Canada Southern Railway (CSR), near Essex, Essex County. The species was well established, locally common along the edge of the tracks, and spreading to the adjacent ditch edge. Associates were mainly typical weedy species for this location and habitat: Spreading Dogbane (*Apocynum androsaemifolium* L.), Common Milkweed (*Asclepias syriaca* L.), Wild Carrot (*Daucus carota* L.), Common Teasel (*Dipsacus fullonum* L.), Slender Cottonweed (*Froelichia gracilis* (Hooker) Moquin-Tandon), Butter-and-eggs (*Linaria vulgaris* Miller),

Kentucky Bluegrass (*Poa pratensis* L.), Prickly Russian-thistle (*Salsola tragus* L.), Bouncing-bet (*Saponaria officinalis* L.), goldenrod (*Solidago* sp.), and Yellow Goatsbeard (*Tragopogon dubius* Scopoli). The discovery of *F. gracilis* (Amaranthaceae) at this location also represented an addition to the Canadian flora (Oldham and Sutherland 1988). The CSR was abandoned between 2000 and 2010 (C. Cooper pers. comm. 28 January 2018). The site was revisited by M.J.O. on 24 July 1984 and 16 August 2012 and *H. sphaerocarpum* was found to be still present.

The second discovery of *H. sphaerocarpum* in Ontario was on 17 September 1992 by M.J.O. and J.M. Bowles along the Sydenham River near Arkona, Middlesex County. The population was locally common and growing in a moist prairie remnant along an embankment of the abandoned Grand Trunk Railroad (GTR) Sarnia line with a variety of habitat-specific, provincially and regionally rare native species (Oldham and Brinker 2009; Oldham 2017). These included Big Bluestem (*Andropogon gerardii* Vitman), Prairie Straw Sedge (*Carex suberecta* (Olney) Britton), Stiff Gentian (*Gentianella quinquefolia* (L.) Small), Fringed Gentian (*Gentianopsis crinita* (Froelich) Ma), Sharp-fruited Rush (*Juncus acuminatus* Michaux), Wiry Panicgrass (*Panicum flexile* (Gattinger) Scribner), Old Switch Panicgrass (*P. virgatum* L.), Little Bluestem (*Schizachyrium scoparium* (Michaux) Nash), Carpenter's Square Figwort (*Scrophularia marilandica* L.), Small Skullcap (*Scutellaria parvula* Michaux var. *parvula*), Yellow Indiangrass (*Sorghastrum nutans* (L.) Nash), Prairie Cordgrass (*Sporobolus michauxianus* (Hitchcock) P.M. Peterson & Saarela), and Nodding

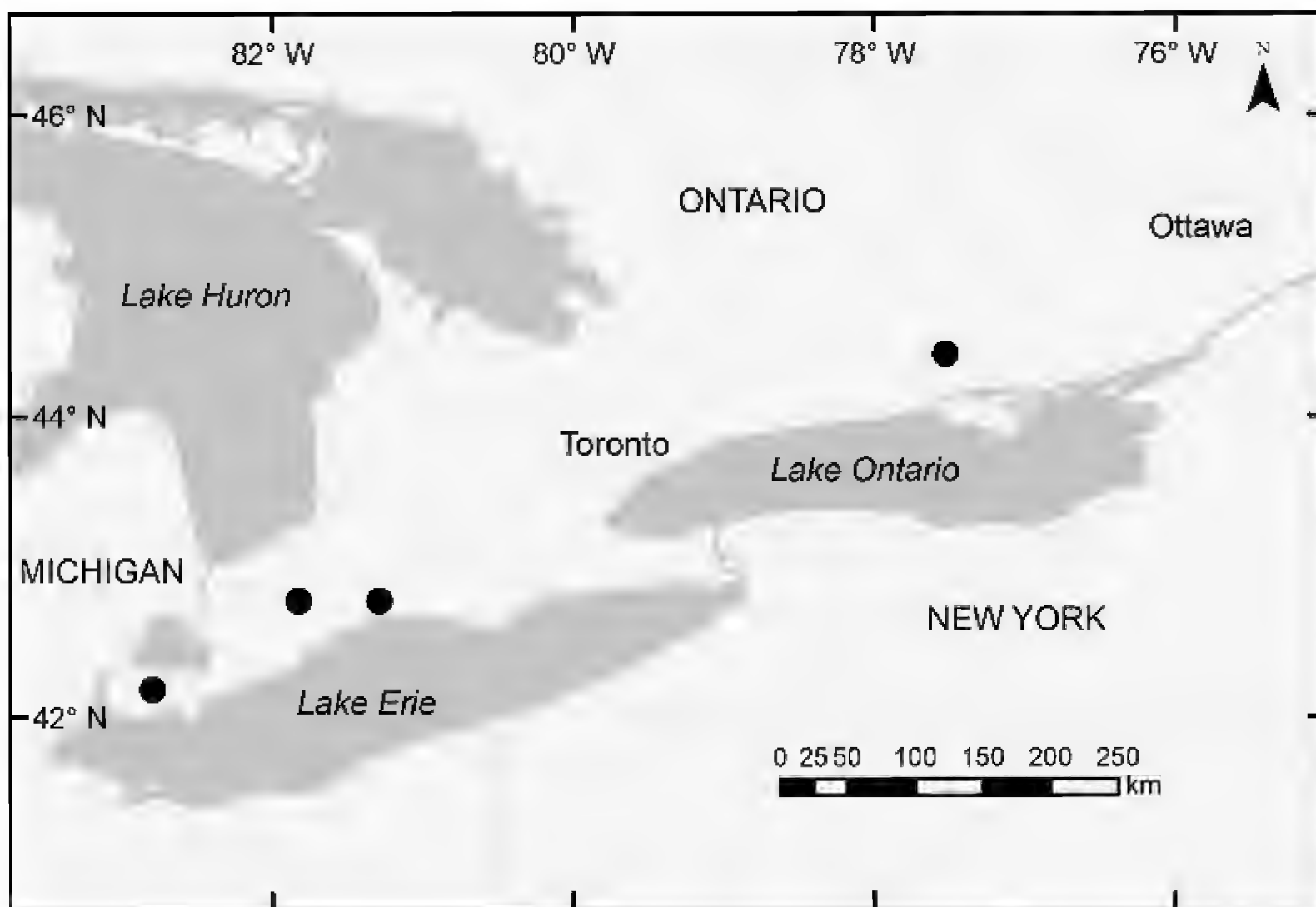


FIGURE 1. New locations for Round-fruited St. John's-wort (*Hypericum sphaerocarpum*) in Ontario, Canada.

Ladies'-tresses (*Spiranthes cernua* (L.) Richard). This population of *H. sphaerocarpum* was considered potentially native to the province by Oldham and Brinker (2009) based on its association with rare and ecologically conservative native species (Oldham *et al.* 1995) of prairie and southern affinity; its location adjacent to a rich floodplain woods containing many other rare native species (Bowles 1992); and its relative proximity (about 175 km) to a presumed native population in southeastern Michigan (Voss and Reznicek 2012).

The third Ontario population to be discovered was found on 27 June 2015 by S. and J. Blaney along a recreational trail occupying the former Pere Marquette Railway near Ivanhoe Station, Hastings County. The site was visited by M.J.O. on 8 July 2015, when the plants were in bud and on 26 July 2015 when they were in flower (Figures 2 and 3). This population was associated with weedy and primarily non-native species typical of the area and habitat, including Yarrow (*Achillea millefolium* L. *sensu lato*), Wild Carrot, Common St. John's-wort (*Hypericum perforatum* L.), Oxeye Daisy (*Leucanthemum vulgare* Lamarck), Garden Bird's-foot Trefoil (*Lotus corniculatus* L.), Tall Goldenrod (*Solidago altissima* L.), Panicked Aster (*Symphotrichum lanceolatum* (Willdenow) G.L. Nesom), Colt's-foot (*Tussilago farfara* L.), and Tufted Vetch (*Vicia cracca* L.). The Hastings County population is located more than 350 km from the next nearest occur-

rence and is the most northern and eastern known population of the species (Robson 1996).

The most recent Ontario discovery of *H. sphaerocarpum* in Ontario was made on 1 September 2017, by W.D.V. along the former Canadian Pacific Railway Ontario and Quebec line near Paynes Mills, Elgin County. The site was revisited on 3 September 2017, when fruiting material was collected. This population consisted of approximately 100 plants and was growing directly in railway ballast on the bed of a decommissioned railway. Associated species were typical of similar decommissioned railways and common in the area; they included knapweed (*Centaurea* spp.), Wild Carrot, Small-flowered Evening Primrose (*Oenothera parviflora* L.), Wild Red Raspberry (*Rubus idaeus* L. ssp. *strigosus* (Michaux) Focke), and Tall Goldenrod.

In the core of its native range, *H. sphaerocarpum* occurs in a variety of habitats including wet and dry prairies, forest openings, roadsides, streambanks, cliffs, and fens (Steyermark 1963; Utech and Iltis 1970; Mohlenbrock 1978; Yatskievych 2006; Wilhelm and Rericha 2017). Some sources indicate an association with calcareous substrates (Svenson 1940; Adams 1962; Cooperrider 1989). The only known Michigan population, which is located in Monroe County, occurs in "openings of shrub thickets on the upper banks of a stream" (Voss and Reznicek 2012).

Some authors (e.g., Steyermark 1963; Mohlenbrock and Evans 1972; Mohlenbrock 1978) have recognized



FIGURE 2. Round-fruited St. John's-wort (*Hypericum sphaerocarpum*) along the former Pere Marquette Railway, now a recreation trail, on 26 July 2015. Photo: M.J. Oldham.

a more southern and eastern, bushy-branched variant of *H. sphaerocarpum*, named var. *turgidum* by Svenson (1940). The variety is characterized by having narrower leaves without lateral veins and with revolute margins. More recent authors have generally not recognized varieties in *H. sphaerocarpum*. Robson (2015) suggests that the narrow-leaved, bushy form from eastern parts of the range (var. *turgidum*) merges with the typical form, and he does not recognize infraspecific taxa. Ontario plants are variable with respect to leaf width, venation, and whether the margins are revolute, which could suggest multiple origins for the Ontario populations.

Adventive populations of *H. sphaerocarpum* can apparently persist for some time. The Elgin County population was discovered 46 years after abandonment of the associated rail line and the Hastings County population was discovered 27 years after abandonment of that line. The Essex County population persisted for at least 29 years after its original discovery and for 2–12 years after abandonment of the CSR line. The Middlesex County population persisted for at least seven years after abandonment of the GTR Sarnia line. Some of these rail lines and their embankment habitat date back to the early 1850s (C. Cooper pers. comm.

28 January 2018) and, thus, assuming that *H. sphaerocarpum* and other prairie-affinity species were not already present in nearby remnant prairie areas no longer extant, they could have become established at any time over the last 180–200 years. Whether *H. sphaerocarpum* is native to Canada may never be fully known. Although some evidence (noted above) suggests that the Middlesex County population is native, the presence of three of the four known populations in weedy situations along railway embankments suggests that the other populations are adventive in Canada.

Voucher specimens

Canada, Ontario, Essex Co., Canada Southern Railway line, 2 km northeast of Essex, 42.181°N, 82.799°W, 19 September 1983, *M.J. Oldham* 4087 (TRTE; identified by A.A. Reznicek); 24 July 1984, *M.J. Oldham* 4390 (MICH, NHIC 03481); 16 August 2012, *M.J. Oldham* 40456 (NHIC 03586, TRT).

Canada, Ontario, Middlesex Co., Sydenham River, 5.7 km south-southeast of Alvinston, 42.772°N, 81.835°W, along an embankment of the abandoned Grand Trunk Railroad Sarnia line, 17 September 1992, *M.J. Oldham and J.M. Bowles* 14419 (MICH, NHIC



FIGURE 3. Close-up of flowers of Round-fruited St. John's-wort (*Hypericum sphaerocarpum*). Photo: M.J. Oldham.

03535); 13 July 1993, *M.J. Oldham and J.M. Bowles 15136* (NHIC 03484).

Canada, Ontario, Hastings Co., former Pere Marquette Railway now recreation trail, 5 km west of Ivanhoe Station, 44.413°N, 77.528°W, 27 June 2015, *S. Blaney and J. Blaney* (photos iNaturalist: <https://www.inaturalist.org/observations/4621216>); 8 July 2015, *M.J. Oldham 43039* (CAN, TRT); 26 July 2015, *M.J. Oldham 43092* (CAN, DAO, MICH, NHIC 03379, TRT).

Canada, Ontario, Elgin Co., 2 km southwest of Paynes Mills, along the former Canadian Pacific Railway Ontario and Quebec line, 42.773°N, 81.294°W, 1 September 2017, *W.D. Van Hemessen* (photos iNaturalist: <https://www.inaturalist.org/observations/7747872>); 3 September 2017, *W.D. Van Hemessen 114* (NHIC 03430).

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Diversity and conservation status of lichens and allied fungi in the Greater Toronto Area: results from four years of the Ontario BioBlitz

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Abstract

Bioblitzes are typically 24-hour biological surveys of a defined region carried out by taxonomic specialists, citizen scientists, and the general public. The largest in Canada is the Ontario BioBlitz, an annual event held in the Greater Toronto Area (GTA). Between 2013 and 2016, we examined the feasibility of including lichens and allied fungi in the Ontario BioBlitz. These taxa are often overlooked, understudied, and taxonomically difficult. We completed a bioblitz in each of the four major watersheds in the GTA and recorded 138 species in 72 genera which, combined with all previous collections, totals 180 species in 88 genera in the area. Thirteen of the species we collected are provincially ranked as S1 (critically imperilled), S2 (imperilled), or S3 (vulnerable). We collected *Lecanora carpineae* for the first time in Ontario. Our results provide a baseline list of GTA lichens that can be used for monitoring. This is one of the first detailed lichen surveys of a major North American urban area and it demonstrates that rapid bioblitz surveys are proficient in capturing lichen diversity despite their inconspicuous nature and the advanced microscopy and chemical analyses required for their identification.

Key words: Biogeography; biodiversity; conservation; citizen science; rare species; BioBlitz Canada

Introduction

Bioblitzes are biological surveys that are spatially defined and temporally limited, usually within a 24-hour period. The term bioblitz was introduced in 1996 by the United States National Park Service and popularized by Edward O. Wilson in 1999 (Shorthouse 2010). Bioblitzes are designed to document all living things in a particular area, and to include taxonomic specialists with the general public or citizen scientists in a meaningful and educational experience (Holden 2003; Scanlon *et al.* 2014). The value of a bioblitz to the understanding and conservation of biodiversity was described by Silvertown (2009) and Donnelly *et al.* (2014). Since 2003, at least 85 peer-reviewed articles mention the term bioblitz, with the vast majority lauding the method as a needed component for future biodiversity monitoring projects (Wheeler *et al.* 2012; Laforest *et al.* 2013; Telfer *et al.* 2015; Wei *et al.* 2016). Data gathered at a bioblitz are important for developing the biological knowledge of an area and they provide a baseline that can be used to monitor changes. For example, species have been discovered at bioblitzes that are new to science (Strongman and White 2011; Bird and Bamber 2013), represent major range extensions (McAlpine *et al.* 2012; Miller *et al.* 2012; Ridling *et al.* 2014; McMullin *et al.* 2015; Ratzlaff *et al.* 2016; Tucker and Rehan 2017; McMullin

2018), and have provided new information on the spread of invasive species (Miller 2016). In honour of the 2009 Saint Mary's University Bioblitz held in the Blue Mountain-Birch Cove Wilderness Area (Nova Scotia), a new species of fungus found in the stomach of a mayfly was named *Trifoliellum bioblitzii* (Strongman and White 2011).

The Ontario BioBlitz Program, led by the Royal Ontario Museum, has held six annual events since 2012 in the Greater Toronto Area (GTA). The GTA is the largest urban area in Canada with a population of almost 6.5 million (Statistics Canada 2017). Each major watershed in the GTA, delineated by ravine system and river complex, was surveyed. Approximately 3500 species have been identified including two species of spider that are new to Canada (*Myrmarachne formicaria* de Geer and *Pholcus opilionoides* Schrank) and over 40 species assessed by the Committee on the Status of Endangered Wildlife in Canada (Ontario BioBlitz 2017). Each event included between 200 and 300 taxonomic specialists, and an equal number of citizen scientists. To increase the scope of taxonomic expertise, the Ontario BioBlitz Program leverages partnerships among academic institutions (e.g., University of Toronto and the University of Guelph), non-government organizations (e.g., Ontario Nature), and governmental agencies (e.g., Canadian

Museum of Nature, Parks Canada, and the Toronto Zoo). All events include some component of public engagement, whether it is direct mentorship by taxonomic specialists or more general information provided at base camp by partner organizations. All data collected during the Ontario BioBlitz Program are made available on the iNaturalist Canada platform (www.inaturalist.ca) and, via Canadensys, to the Global Biodiversity Information Facility. Based on the number of volunteers and the number of species documented, the Ontario BioBlitz Program is one of the largest bioblitz initiatives in the world. The program includes taxonomic specialists in as many fields as possible, including those focussed on uncommonly studied groups such as lichens.

Lichens are composite organisms comprised primarily of a mycobiont (fungus) and photobiont (an alga or a cyanobacterium or both; McMullin and Anderson 2014). Unlike vascular plants, they lack a protective cuticle that allows them to acquire nutrients directly from the atmosphere and precipitation that washes over them (Richardson 1975; Richardson and Cameron 2004). As a result, airborne chemicals are also taken in by lichens, which have a range of tolerances, making it possible to correlate air quality with the presence of particular species (Richardson 1992; Cameron *et al.* 2007; McMullin *et al.* 2017). A study in three cities in southern Ontario showed that urbanization is negatively correlated with lichen diversity (McMullin *et al.* 2016). The GTA is the largest urbanized area in Canada, which has likely had a considerable impact on lichen diversity. Nevertheless, no baseline data exist for lichens, other than a small number of scattered historical collections (Wong and Brodo 1992), so changes cannot be ascertained. Bioblitzes are a way to quickly develop baseline data for a region. Once a baseline is established for lichens, it can be an efficient way to monitor air quality and the effects of urbanization on biodiversity.

Lichens and allied fungi, however, are often poorly represented at bioblitzes. They are typically overlooked because many species are minute and inconspicuous. Lichenology has also traditionally been an academic pursuit that limited the number of people with access to the resources and skills required for lichen identification. It was only recently that the first detailed identification guide with colour illustrations of North American lichens was published (Brodo *et al.* 2001), with more regional illustrated guides produced in the years that followed (e.g., Hinds and Hinds 2007; McCune and Geiser 2009; McMullin and Anderson 2014). Nonetheless, difficulty in locating smaller species plus the advanced microscopy and chemical analyses required for lichen identification (Brodo *et al.* 2001) continues to limit their inclusion in rapid surveys such as bioblitzes.

The aim of our study was to target lichens during the Ontario BioBlitz over four years in each of the four major watersheds in the GTA. Our objectives were to identify the areas most likely to contain a rich lichen

biota, collect all species encountered, reliably identify specimens in a laboratory, deposit specimens in a public herbarium, and compare our findings with species that have been historically collected in the GTA. The results will provide the first baseline list of lichens in the GTA, one of the first detailed urban lichen surveys in North America, and demonstrate the ability of a 24-hour bioblitz to capture lichen diversity.

Study Area

The GTA is located in southern Ontario, Canada on the north shore of Lake Ontario (Figure 1). It covers 7127 km² and includes the City of Toronto surrounded by the four Regional Municipalities of Durham, York, Peel, and Halton. With a total human population of 6 417 516 (2016 figures), the GTA is the most populous region in Ontario (total population 13 448 494) and Canada (35 151 728; Statistics Canada 2017). Population densities range from 255.9 people/km² in the Durham region to 4334.4 people/km² in the City of Toronto (Statistics Canada 2017). The GTA is bordered by (from east to west) the Kawartha Lakes, Lake Simcoe, and the Niagara Escarpment. This area is sometimes referred to as the Greater Toronto Bioregion (Shoreline Regeneration Work Group 1991). Despite being a dense urban centre, it contains a number of conserved parks and natural areas as well as farmland, and overlaps with a portion of the Oak Ridges Moraine as part of the Greenbelt (Milne *et al.* 2006). Rouge National Urban Park for example, found at the intersection of the City of Toronto, York, and Durham, is one of the largest urban parks in the world, and aims to conserve both natural areas and agricultural lands. Of the 80 km² of parks within the City of Toronto, about 50% are naturalized areas (J. Weninger pers. comm. 2017). Within Toronto, there are 307 km of creeks and rivers, over 200 km of trails, and an estimated 10 million trees in the city core (Johnson 2012).

The Oak Ridges Moraine was exposed when the Late Wisconsin glacier retreated about 12 000 years ago (Barnett *et al.* 1998). The bedrock of the GTA however formed about 450 million years ago, and is comprised mainly of shale, dolomitic siltstone, and limestone. Outside of the densely urbanized zones, the soil is mostly clayey or sandy silt, and is often designated as till due to recent agricultural activities. In the most populous areas, the soil type varies widely, from gravel and sand to silty clay depending on location and proximity to large bodies of water (Sharpe 1980). The drainage and pH of the soil ranges broadly as well, and this variety leads to many different biological community types throughout the city (Smith *et al.* 2015). The mean annual temperature is 9.4°C with a mean monthly low of -3.7°C in January and a high of 22.3° in July. The mean annual precipitation is 831.1 mm, with rainfall constituting 86% of the total (Government of Canada 2017). Most of the rain falls in May, August, and September, while most of the snow falls between Decem-

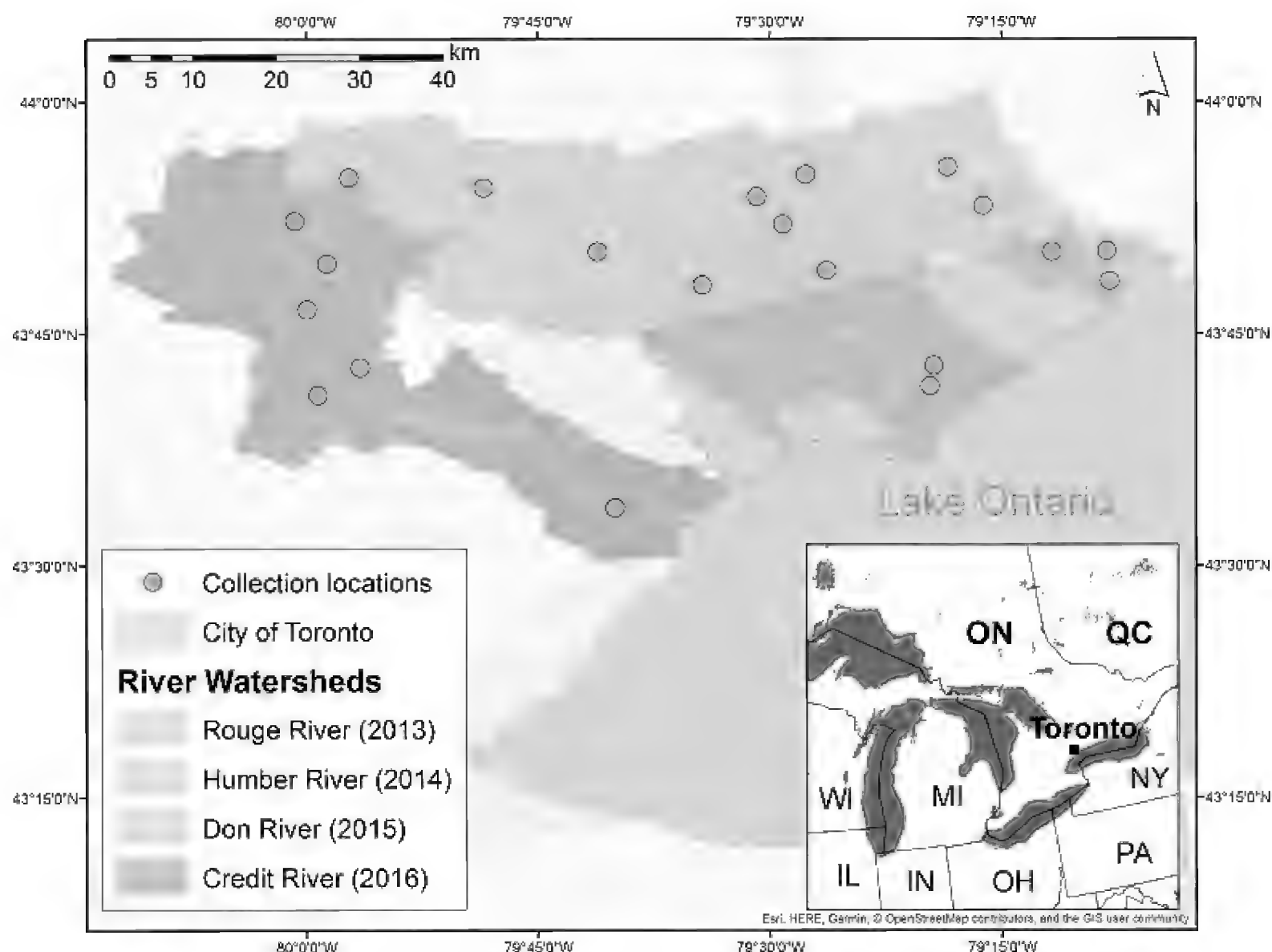


FIGURE 1. Lichen collection sites in the four watersheds surveyed in the Greater Toronto Area, Ontario, Canada.

ber and March (Government of Canada 2017). The province of Ontario has been improving air quality in recent decades, and there has been a considerable improvement since 2008, as well as fewer smog advisories (Government of Ontario 2014). Nitrogen oxides, sulphur dioxide, carbon monoxide, and fine particulate matter have decreased in concentration and emission by over 10% between 2006 and 2015, while ozone increased 3% (Government of Ontario 2015a). Some areas of the GTA with high vehicular traffic have poorer air quality than areas outside the city (Government of Ontario 2015a). Overall, air quality in the GTA is highly variable depending on proximity to highways, industrial sectors, and other point sources of pollution (Government of Ontario 2015a).

The southern edge of the GTA is Carolinian forest which is dominated by trees such as American Beech (*Fagus grandifolia* Ehrhart), hickory (*Carya* spp.), maple (*Acer* spp.), and oak (*Quercus* spp.). The tree communities in the GTA are also influenced by the Great Lakes-St. Lawrence forest to the north, which includes species such as Red Pine (*Pinus resinosa* Aiton), Eastern White Pine (*Pinus strobus* L.), and Yellow Birch (*Betula alleghaniensis* Britton; Government of Ontario 2015b; Smith *et al.* 2015). Prior to logging and urbanization, grasslands were present in the area. To-

day, the only remaining oak savannah grassland in the GTA is located in High Park in the west end of Toronto. The anthropogenic impacts on the land combined with the variety of soil types, slight changes in topography, and influences of the watersheds has meant that the GTA is a hotspot for biodiversity with many habitats and microhabitats supporting a wide range of wildlife (Smith *et al.* 2015).

Methods

Sampling and storage

We sampled each of the four major watersheds in the GTA over a 24-hour period in June, 2013 (Rouge River), 2014 (Humber River), 2015 (Don River), and 2016 (Credit River; Figure 1). The areas we visited were selected because they were among the least disturbed or developed in each watershed and they appeared to have a comparatively high diversity of ecosystems and habitat types, based on satellite images and ecosystem classification maps. To maximize the area covered, we split into two groups each year, one lead by R.T.M. and the other by K.D. Our sampling protocol followed the methods of Newmaster *et al.* (2005), who showed that examining large areas (referred to as floristic habitat sampling) captures cryptogam diversity more effectively than establishing smaller representative plots. Using

floristic habitat sampling, we attempted to examine all distinct restricted mesohabitats in each area (e.g., streams, rock outcrops, cliffs, swamps) as well as many microhabitats (e.g., snags, tree bases, different rock types). This method was also used by Selva (1999, 2003) to sample lichens. He refers to it as an “intelligent meander” as it allows more time to be spent in areas that are likely to have a higher number of lichen species. We collected specimens on trees, wood, and soil with a knife and those on rock were collected with a 1.8 kg hammer and cold chisel. Our wet specimens were air dried for three days and then stored in acid free packets. All specimens were identified in the lichen laboratory at the Biodiversity Institute of Ontario in Guelph or the Canadian Museum of Nature in Ottawa.

Identification

We used standard microscopy and chemical spot tests to identify specimens following Brodo *et al.* (2001). We also used an ultraviolet light chamber to examine secondary metabolites. Using thin-layer chromatography, we further assessed chemical properties in solvents A, B', and C (Culberson and Kristinsson 1970; Orange *et al.* 2001). We deposited our specimens at the Canadian Museum of Nature (CANL) and the Biodiversity Institute of Ontario Herbarium (OAC) at the University of Guelph (see Appendix S1 for collection and accession details).

Historical records

We obtained data on lichens and allied fungi previously collected in the GTA from various sources: Wong and Brodo (1990, 1992), a physical search of the national herbarium at the Canadian Museum of Nature, and an electronic search of five botanical databases (Canadensys, Canadian Museum of Nature, Consortium of North American Lichen Herbaria, Biodiversity Institute of Ontario, and the Global Biodiversity Information Facility). Reports of dubious species that we did not collect were borrowed and verified or revised, if they were available.

Conservation status

Ontario conservation status ranks (S-ranks) are non-legal designations set by the Ontario Natural History Information Centre (NHIC) and are based on guidelines developed by NatureServe (NatureServe 2015). Species with distributions and frequencies that are believed to be well understood receive a rank between 1 and 5: 1 = critically imperilled, 2 = imperilled, 3 = vulnerable, 4 = apparently secure, 5 = secure. Other species receive one of the following designations: NR = not ranked, U = unrankable (due to a lack of information), ? = rank uncertain.

Results

We collected 138 lichen and allied fungus species in the GTA. These data, combined with all previous collections, total 180 species in 88 genera (see Annotated Species List). Ninety-five (51%) of these species

are microlichens (crustose species that includes all allied fungi) and 85 (47%) are macrolichens (59 foliose and 26 fruticose). Green algae are the primary photobionts in 152 (84%) species, while 15 (8%) species have cyanobacteria as their primary photobiont, and 13 (7%) species are nonlichenized fungi traditionally treated with lichens. Four (2%) species are lichenicolous. Nine (5%) species are calicioids, six of which are nonlichenized, and one of which is lichenicolous, *Sphinctrina anglica* Nyl. *Lecanora carpinea* (L.) Vain. was collected for the first time in Ontario (McMullin 2018).

We located the highest number of lichens and allied fungi at the Forks of the Credit River Provincial Park (74 species), Glen Haffy Conservation Area (49 species), and the Belfountain Conservation Area (35 species; Figure 1).

Conservation status

One hundred and forty of the 180 species in the GTA have been assigned conservation ranks. Twenty-two species have a rank of S1 to S3—bolded species were collected during the bioblitzes and non-bolded are historical collections: S1. ***Acrocordia cavata* (Ach.) R.C. Harris** and *Gyalecta fagicola* (Hepp ex Arnold) Kremp.; S1S2. *Placidium lachneum*; S1S3. ***Melanelixia subargentina* (Nyl.) O. Blanco, A. Crespo, Divakar, Essl., D. Hawksw. & Lumbsch**, *Phaeophyscia hirsuta* (Mereschk.) Essl., and *Scytinium teretiusculum* (Wallr.) Otálora, P.M. Jørg. & Wedin; S2. *Bacidia laurocerasi* (Delise ex Duby) Zahlbr.; S2S3. ***Chaenothecopsis debilis* (Turner & Borrer ex Sm.) Tibell**, *Coenogonium luteum* (Dicks.) Kalb & Lücking, ***Flavopunctelia sor-edica* (Nyl.) Hale**, *Gyalecta jenensis* (Batsch) Zahlbr., ***Lecania naegelii* (Hepp) Diederich & v.d. Boom**, ***Phaeocalicium polyporaeum* (Nyl.) Tibell**, *Phaeophyscia ciliata* (Hoffm.) Moberg, and ***Viridothelium virens* (Tuck. ex E. Michener) Lücking, M.P. Nelsen & Aptroot**; S3. *Anaptychia palmulata* (Michx.) Vain., ***Catillaria nigroclavata* (Nyl.) Schuler**, *Coenogonium pineti* Lücking & Lumbsch, *Placidium squamulosum* (Ach.) Breuss, and *Sphinctrina anglica*; and S3S4. *Bacidia bagliettoana* (A. Massal. & De Not.) Jatta and ***Phaeophyscia kairamoi* (Vain.) Moberg**. The remainder of the species are either secure, apparently secure, possibly extirpated or are not ranked: S4 = 26, S4S5 = 13, S5 = 78, S5? = 1, SU = 6, SH = 1, and SNR = 33. The S-ranks presented here may have changed during a recent update for Ontario lichens by the NHIC (available at: <https://www.ontario.ca/page/get-natural-heritage-information>). These updates were not available in time to include in the present manuscript.

Annotated Species List

The list is arranged alphabetically by genus and species. Species authors are cited following Brummitt and Powell (1996) or the 21st edition of the North American Lichen Checklist (Esslinger 2016). Nomenclature mostly follows the 21st edition of the North American Lichen Checklist (Esslinger 2016). Deviance from

Esslinger's list represents the opinion of the authors. Names in bold represent collections made during the watershed bioblitzes while those not in bold represent previous collections made in the GTA by different collectors. Non-lichenized fungi traditionally treated with lichens are preceded by a dagger (†). New provincial records are preceded by an asterisk (*). Substrates follow species names, followed by watershed acronyms (CR = Credit River, DR = Don River, HR = Humber River, RR = Rouge River), and provincial conservation status ranks (*S-ranks*).

***Acarospora fuscata* (Schrad.) Arnold** – Saxicolous on non-calcareous rock. CR, HR, RR. S5.

***Acarospora glaucocarpa* (Ach.) Körb.** – Saxicolous on calcareous rock. CR. S4S5.

***Acarospora moenium* (Vain.) Räsänen** – Saxicolous on calcareous boulders and concrete. DR, HR. SNR.

***Acrocordia cavata* (Ach.) R.C. Harris** – Corticolous on a deciduous snag and *Populus*. CR, DR. S1.

***Alyxoria varia* Pers.** – Corticolous on a deciduous snag, *Acer*, and *Fraxinus*. CR, HR. S4.

***Amandinea dakotensis* (H. Magn.) P. May & Sheard** – Corticolous on a deciduous snag. DR. S4.

***Amandinea punctata* (Hoffm.) Coppins & Scheid.** – Corticolous on *Acer nigrum* and *P. strobus*. Lignicolous on exposed wood and a *Thuja* fence. CR, DR, HR, RR. S5.

***Anaptychia palmulata* (Michx.) Vain.** – Terricolous. *White 316* (CANL) (Wong and Brodo 1992). S3.

†***Arthonia caudata* Willey** – Corticolous on *P. strobus*. CR, DR, HR, RR. SNR.

***Arthonia helvola* (Nyl.) Nyl.** – Corticolous on *B. alleghaniensis* and *Betula papyrifera*. CR, HR, RR. SNR.

***Arthonia radiata* (Pers.) Ach.** – Corticolous on *Acer*. CR. S5.

***Arthothelium spectabile* (Flot.) A. Massal.** – Corticolous on *Acer saccharum*. (Wong and Brodo 1992). DR. SU.

***Aspicilia cinerea* (L.) Körb.** – Saxicolous on an exposed boulder. HR. S4S5.

***Bacidia bagliettoana* (A. Massal. & De Not.) Jatta** – Terricolous. (Wong and Brodo 1992). S3S4.

***Bacidia laurocerasi* (Delise ex Duby) Zahlbr.** – Corticolous on *Thuja occidentalis*. *Cain s.n.* (F). DR. S2.

***Bacidia rubella* (Hoffm.) A. Massal.** – Corticolous on *T. occidentalis*. HR. S4.

***Bacidia schweinitzii* (Fr. ex Tuck.) A. Schneid.** – Corticolous. (Wong and Brodo 1992). HR. S5.

***Bacidia* sp.** – Corticolous on *A. saccharum*. HR. SNR.

***Bacidia suffusa* (Fr.) A. Schneid.** – Corticolous. (Wong and Brodo 1992). S4.

***Bilimbia sabuletorum* (Schreb.) Arnold** – Bryicolous; corticolous on *T. occidentalis*; saxicolous. CR, HR. S5.

***Caloplaca arenaria* (Pers.) Müll. Arg.** – Saxicolous on non-calcareous rock. CR, HR. S5.

***Caloplaca cerina* (Ehrh. ex Hedw.) Th. Fr.** – Corticolous on *Fraxinus*, *Populus*, *Populus balsamifera*, and *Populus tremuloides*. CR, DR, HR. S5.

***Caloplaca feracissima* H. Magn.** – Saxicolous on calcareous rock and concrete. CR, DR, HR, RR. S5.

***Caloplaca flavovirescens* (Wulfen) Dalla Torre & Sarnth.** – Saxicolous on a calcareous boulder and a rock wall. CR. S5.

***Caloplaca holocarpa* (Hoffm. ex Ach.) A.E. Wade** – Saxicolous on a calcareous rock. CR, HR. S5.

***Caloplaca pyracea* (Ach.) Th. Fr.** – Corticolous on *Fraxinus*, *Populus*, *P. balsamifera*, *P. tremuloides*. CR, DR, HR, RR. SNR.

***Candelaria concolor* (Dicks.) Stein** – Corticolous on *Acer*, *A. saccharum*, a deciduous snag, and *Fraxinus americana*. CR, DR, HR, RR. S5.

***Candelariella aurella* (Hoffm.) Zahlbr.** – Saxicolous on calcareous rock and concrete. CR, DR, HR, RR. S5.

***Candelariella efflorescens* R.C. Harris & W.R. Buck** – Corticolous on *B. papyrifera*; lignicolous on an exposed fence and a *T. occidentalis* snag. CR, DR, RR. S5.

***Candelariella vitellina* (Hoffm.) Müll. Arg.** – Saxicolous on non-calcareous rock. HR. S5.

***Catillaria nigroclavata* (Nyl.) Schuler** – Corticolous on *Elaeagnus angustifolia*, a fallen branch, *P. strobus*, and a snag. CR, DR, HR, RR. S3.

***Chaenotheca* sp.** – Lignicolous (stump). DR. SNR.

***Chaenotheca balsamconensis* J.L. Allen & McMullin** – Fungicolous on *Trichaptum abietinum*. CR. SNR.

†***Chaenothecopsis* sp.** – Lignicolous on a snag. HR. SNR.

†***Chaenothecopsis debilis* (Turner & Borrer ex Sm.) Tibell** – Lignicolous on a stump. CR. S2S3.

***Chrysothrix caesia* (Flot.) Körb.** – Corticolous on *A. saccharum*, *E. angustifolia*, *Fraxinus*, and *Quercus rubra*. CR, DR, HR, RR. S5.

***Cladonia cariosa* (Ach.) Spreng.** – Terricolous. (Wong and Brodo 1992). S5.

***Cladonia cenotea* (Ach.) Schaer.** – Lignicolous on an old stump. HR. S5.

***Cladonia chlorophaea* (Flörke ex Sommerf.) Spreng.** – Corticolous; lignicolous on a log; saxicolous on a mossy rock. CR, HR, RR. S5.

***Cladonia coniocraea* (Flörke) Spreng.** – Lignicolous on a log. RR. SU.

Cladonia crispata (Ach.) Flot. – Lignicolous on a stump. HR. S5.

Cladonia cristatella Tuck. – Lignicolous on a log and a stump. HR, RR. S5.

Cladonia cryptochlorophaea Asahina – Saxicolous. HR. SU.

Cladonia decorticata (Flörke) Spreng. – Lignicolous on a log. S4.

Cladonia digitata (L.) Hoffm. – Lignicolous on a stump. HR. S4S5.

Cladonia fimbriata (L.) Fr. – Lignicolous on a log. CR. S5.

Cladonia furcata ssp. *furcata* (Huds.) Schrad. – Terricolous. (Wong and Brodo 1992). S5.

Cladonia gracilis ssp. *turbinata* (Ach.) Ahti – Terricolous. (Wong and Brodo 1992). CR. S5.

Cladonia humilis (With.) J.R. Laundon – Terricolous. (Wong and Brodo 1992). S4?

Cladonia incrassata Flörke – Lignicolous on a stump. HR. S4.

Cladonia macilenta var. *bacillaris* (Genth) Schaer. – Lignicolous on a log, a stump, and a *Thuja* fence. CR, HR, RR. S5.

Cladonia ochrochlora Flörke – Corticolous on the base of a tree; lignicolous on a stump; saxicolous on a mossy rock. CR, HR. S5.

Cladonia pocillum (Ach.) Grognot – Terricolous on thin soil over rock. CR, RR. S4S5.

Cladonia pyxidata (L.) Hoffm. – Lignicolous on a log. RR. S5.

Cladonia ramulosa (With.) J.R. Laundon – Corticolous on a *Pinus* stump. (Wong and Brodo 1992). SNR.

Cladonia rei Schaer. – Terricolous and on soil on a fence rail. CR, HR. S5.

Cladonia scabriuscula (Delise) Nyl. – Lignicolous on an old stump. HR. S5.

†*Clypeococcum hypocenomyces* D. Hawksw. – Lichenicolous on *Hypocenomyce scalaris*. HR. SNR.

Coenogonium luteum (Dicks.) Kalb & Lücking – Corticolous on *Thuja*. (Wong and Brodo 1992). S2S3.

Coenogonium pineti Lücking & Lumbsch – Lignicolous on a charred stump and a log; terricolous. CR, RR. S3.

Cyphelium tigillare (Ach.) Ach. – Lignicolous on an old *Thuja* fence. CR. S4.

Dictyocatenuata alba Finley & E.F. Morris – Corticolous on *B. alleghaniensis* and a *B. papyrifera* snag. CR, HR, RR. SNR.

Dimelaena oreina (Ach.) Norman – Saxicolous on non-calcareous rock. HR. S4.

Diplotomma venustum (Körb.) Körb. – Saxicolous on a rock wall. CR. SNR.

Enchylium tenax (Sw.) – Terricolous. (Wong and Brodo 1992). S4.

Evernia mesomorpha Nyl. – Corticolous on a dead *Rhus typhina* branch, a deciduous snag, and *Larix laricina*. CR, HR. S5.

Flavoparmelia caperata (L.) Hale – Corticolous on *Acer*, *A. saccharum*, a fallen deciduous tree, an unknown ornamental tree, a snag, and *Ulmus*; lignicolous on fence rails. CR, DR, HR, RR. S5.

Flavopunctelia flaventior (Stirt.) Hale – Corticolous on *F. americana* and *Populus grandidentata*; lignicolous on a *Thuja* fence post. CR, DR, HR. S5.

Flavopunctelia soledica (Nyl.) Hale – Corticolous on a deciduous tree, *F. americana*, and on *Fraxinus*. CR, HR. S2S3.

Graphis scripta (L.) Ach. – Corticolous on *Acer*, *A. rubrum*, *A. saccharum*, and on *B. alleghaniensis*. CR, DR, HR. S5.

Gyalecta fagicola (Hepp ex Arnold) Kremp. – Corticolous on *Ulmus*. Cain s.n. (NY). CR. S1.

Gyalecta jenensis (Batsch) Zahlbr. – Saxicolous on calcareous rock. CR. S2S3.

Hyperphyscia adglutinata (Flörke) H. Mayrh. & Poelt – Corticolous on *Acer*, *A. saccharum*, *E. angustifolia*, and on *Quercus*. CR, DR, HR, RR. S4.

Hypocenomyce scalaris (Ach.) M. Choisy – Corticolous on *P. strobus*; lignicolous on a stump. DR, HR. S5.

Hypogymnia physodes (L.) Nyl. – Corticolous on a snag. HR. S5.

†*Illosporopsis christiansenii* (B.L. Brady & D. Hawksw.) D. Hawksw. – Lichenicolous on *Physcia*, and *Physcia millegrana*. CR, HR. SNR.

†*Julella fallaciosa* (Arnold) R.C. Harris – Corticolous on *Acer*, *Acer saccharum*, *Betula*, and *B. papyrifera*. CR, DR, HR, RR. SNR.

Lecania croatica (Zahlbr.) Kotlov – Corticolous on *Acer*, *Acer rubrum*, *A. saccharum*, a deciduous tree, *F. grandifolia*, and *Tilia*. CR, DR, HR. SNR.

Lecania naegelii (Hepp) Diederich & v.d. Boom – Corticolous on *Fraxinus*, *F. americana*, and on *P. tremuloides*. DR, HR, RR. S2S3.

Lecanora albellula Nyl. – Corticolous. (Wong and Brodo 1992). SNR.

Lecanora allophana f. *sorediata* Nyl. – Corticolous on *P. tremuloides*. HR. S5.

**Lecanora carpineae* (L.) Vain. SNR – Corticolous. DR. SNR.

Lecanora hybocarpa (Tuck.) Brodo – Corticolous on *A. rubrum* and a deciduous snag. CR, HR. S4S5.

Lecanora polytropa (Hoffm.) Rabenh. – Saxicolous on non-calcareous rock. HR, RR. S5.

Lecanora pulicaris (Pers.) Ach. – Corticolous on *P. strobilus*. CR, HR. S5.

Lecanora sambuci (Pers.) Nyl. – Corticolous on *Fraxinus*, *F. americana*, *Populus*, and *P. tremuloides*. CR, DR, HR, RR. SNR.

Lecanora symmicta (Ach.) Ach. – Corticolous on *A. rubrum* and *P. strobilus*; lignicolous on a *Thuja* fence rail. CR, DR, HR. S5.

Lecanora thysanophora Harris – Corticolous on *Acer*, a deciduous snag, and *Q. rubra*. CR, DR, HR, RR. S5.

Lecidella stigmata (Ach.) Hertel & Leuckert – Saxicolous on concrete and a rock wall. CR, HR. S5.

Lepraria finkii (B. de Lesd.) R.C. Harris – Corticolous on *Salix* and *T. occidentalis*; lignicolous on a log and a stump. CR, DR, HR, RR. SNR.

Lepraria neglecta (Nyl.) Erichsen – Corticolous on *Tsuga canadensis*. HR. S4S5.

Leptogium byssinum (Hoffm.) Zwackh ex Nyl. – Terricolous on clay soil. (Wong and Brodo 1992). SH.

Lithothelium hyalosporum (Nyl.) Aptroot – Corticolous. (Wong and Brodo 1992). S4.

Lobaria quercizans Michx. – Corticolous. (Wong and Brodo 1992). CR. S4S5.

Megalaria laureri (Hepp ex Th. Fr.) Hafellner – Corticolous on *Fagus*. (Wong and Brodo 1992). SNR.

Melanelixia subargentifera (Nyl.) O. Blanco, A. Crespo, Divakar, Essl., D. Hawksw. & Lumbsch – Corticolous on *P. tremuloides*. HR. S1S3.

Melanelixia subaurifera (Nyl.) O. Blanco, A. Crespo, Divakar, Essl., D. Hawksw. & Lumbsch – Corticolous on a dead *R. typhina* branch, *F. americana*, a snag, and *T. occidentalis*; lignicolous on a *Thuja* fence rail; saxicolous on exposed boulders. CR, DR, HR, RR. S5.

Micarea prasina s. lat. Fr. – Corticolous on *T. occidentalis*. CR. SNR.

Micarea peliocarpa (Anzi) Coppins & R. Sant. – Lignicolous on a stump. HR. S4S5.

Montanelia soreliata (Ach.) Goward & Ahti – Saxicolous on an exposed boulder. HR. S5.

†*Mycocalicium subtile* (Pers.) Szatala – Lignicolous on a decorticated stump and a snag. CR. S4S5.

Myelochroa aurulenta (Tuck.) Elix & Hale – Corticolous on *Acer*. CR. S5.

Myriolecis dispersa (Pers.) Śliwa, Zhao Xin & Lumbsch – Saxicolous on calcareous rock and concrete. DR, HR, RR. SU.

Myriolecis hagenii (Ach.) Ach. – Lignicolous on a *Thuja* fence and a wooden sign post. CR, HR. S5?

Myriolecis semipallida H. Magn. – Saxicolous on concrete. CR. SNR.

Ochrolechia arborea (Kreyer) Almb. – Corticolous on a living fallen *T. occidentalis* and a snag. CR, HR, RR. S4S5.

†*Ovicuculispora parmelliae* (Berk. & Curt.) Etayo – Lichenicolous on *Physcia* and *Physcia stellaris*. CR, DR. SNR.

Parmelia sulcata Taylor – Corticolous on *A. saccharum*, *F. americana*, a snag, and *Ulmus*; lignicolous on a fence rail; saxicolous on exposed boulders. CR, DR, HR, RR. S5.

Peltigera canina (L.) Willd. – Corticolous on a rotting log. (Wong and Brodo 1992). HR. S5.

Peltigera didactyla (With.) Laundon – Terricolous. (Wong and Brodo 1992). S5.

Peltigera elisabethae Gyeln. – Terricolous. (Wong and Brodo 1992). HR. S5.

Peltigera evansiana Gyeln. – Terricolous. CR. S4S5.

Peltigera horizontalis (Huds.) Baumg. – Terricolous. (Wong and Brodo 1992). HR. S4S5.

Peltigera lepidophora (Nyl. ex Vain.) Bitt. – Terricolous on sandy soil. (Wong and Brodo 1992). S4.

Peltigera leucophlebia (Nyl.) Gyeln. – Terricolous. (Wong and Brodo 1992). S4.

Peltigera neckeri Hepp ex Müll. Arg. – Terricolous. (Wong and Brodo 1992). S5.

Peltigera neopolydactyla (Gyeln.) Gyeln. – Terricolous. (Wong and Brodo 1992). S5.

Peltigera praetextata (Flörke ex Sommerf.) Zopf – Lignicolous on a moss-covered log; saxicolous on a mossy rock; terricolous on a moss-covered rock. CR, HR, RR. S5.

Peltigera rufescens (Weiss) Humb. – Terricolous on well-drained soil. CR. S5.

Pertusaria macounii (Lamb) Dibben – Corticolous on *F. grandifolia*. CR. S4.

†*Phaeocalicium curtisii* (Tuck.) Tibell – Corticolous on *R. typhina*. CR, DR, HR. S5.

†*Phaeocalicium polyporaeum* (Nyl.) Tibell – Fungicolous on *Trichaptum biforme*. DR. S2S3.

Phaeophyscia adiastrata (Essl.) Essl. – Bryicolous. CR. S4.

Phaeophyscia ciliata (Hoffm.) Moberg – Corticolous on *Populus*. Darker 5609 (FH). S2S3.

Phaeophyscia hirsuta (Mereschk.) Essl. – Corticolous on *Salix*. (Wong and Brodo 1992). CR. S1S3.

Phaeophyscia kairamoi (Vain.) Moberg – Corticolous on *A. nigrum*. RR. S3S4.

Phaeophyscia orbicularis (Neck.) Moberg – Lignicolous on a picnic table; saxicolous on a boulder. DR, HR, RR. S5.

Phaeophyscia pusilloides (Zahlbr.) Essl. – Corticolous on *Acer*, *A. saccharum*, a deciduous snag, *Fraxinus*, and *Q. rubra*. CR, DR, HR, RR. S5.

Phaeophyscia rubropulchra (Degel.) Essl. – Corticolous on *A. saccharum*, *Crataegus*, and a snag. CR, DR, HR, RR. S5.

Physcia adscendens (Fr.) H. Olivier – Corticolous on *Acer*, *A. saccharum*, *Malus*, *P. strobus*, a snag, and *Ulmus*. CR, DR, HR, RR. S5.

Physcia aipolia (Ehrh. ex Humb.) Fürnr. – Corticolous on *A. nigrum*, a deciduous snag, *Fraxinus*, and *F. americana*. CR, DR, HR, RR. S5.

Physcia dubia (Hoffm.) Lettau – Saxicolous on a boulder. CR, HR. S5.

Physcia millegrana Degel. – Corticolous on *Acer*, *A. saccharum*, *Fraxinus*, *F. americana*, *Malus*, and *Tilia*. CR, DR, HR, RR. S5.

Physcia stellaris (L.) Nyl. – Corticolous on a deciduous snag, *F. americana*, *P. strobus*, and *Q. rubra*; lignicolous on a *Thuja* fence. CR, DR, HR, RR. S5.

Physciella chloantha (Ach.) Essl. – Corticolous on *Acer*, a deciduous snag, *Fraxinus*, and *Ulmus*. CR, DR, HR. S4.

Physciella melanchra (Hue) Essl. – Corticolous on *Acer* and *F. americana*. HR, RR. S4.

Physconia detersa (Nyl.) Poelt – Corticolous on *B. papyrifera* and a snag. CR, DR, HR, RR. S5.

Physconia enteroxantha (Nyl.) Poelt – Corticolous on *Acer*, *A. nigrum*, *Fraxinus*, *F. americana*, and *Ulmus*; saxicolous on boulders. CR, HR, RR. S4.

Placidium lachneum (Ach.) B. de Lesd. – Terricolous. (Wong and Brodo 1992). S1S2.

Placidium squamulosum (Ach.) Breuss – Terricolous. CR. S3.

Placynthium nigrum (Huds.) Gray – Saxicolous on shoreline rocks. CR. S5.

Polychidium muscicola (Sw.) Gray – Corticolous on old *Ulmus* log. Cain 25418 (Det. Hale) (US). HR. SNR.

Porpidia crustulata (Ach.) Hertel & Knoph – Saxicolous. CR. S5.

Porpidia macrocarpa (DC.) Hertel & A.J. Schwab – Saxicolous. CR. S4.

Protoblastenia rupestris (Scop.) J. Steiner – Saxicolous on calcareous rock. CR, RR. S5.

Protoparmelia hypotremella Herk, Spier & V. Wirth – Corticolous on a dead branch. CR. SNR.

Protoparmeliopsis muralis (Schreb.) Rabenh. – Saxicolous on concrete. CR, HR. S5.

Pseudoschismatomma rufescens (Pers.) Ertz & Tehler – Corticolous on *Tilia*. Cain 26826 (det. Harris) (NY). SNR.

Punctelia caseana Lendemer & Hodgkinson – Corticolous. Cain 27122 (det. Lendemer) (CANL). HR. SNR.

Punctelia rudecta (Ach.) Krog – Corticolous on *Acer*, *Crataegus*, a deciduous snag, *T. occidentalis*, and *Q. rubra*; saxicolous on boulders. CR, DR, HR, RR. S5.

Pyrenula pseudobufonia (Rehm) R.C. Harris – Corticolous on *Acer*. (CANL) (Wong and Brodo 1992). HR. S4.

Pyxine soorediata (Ach.) Mont. – Corticolous. (Wong and Brodo 1992). CR. S5.

Ramalina americana Hale – Corticolous on *Picea*. (Wong and Brodo 1992). CR. S5.

Ramalina obtusata (Arnold) Bitter – Corticolous on *Ulmus*. (Wong and Brodo 1992). HR. S4?

Rhizocarpon reductum (Ach.) A. Massal. – Saxicolous on a non-calcareous boulder. HR. SNR.

Rinodina freyi H. Magn. – Corticolous on *Q. rubra*. CR. SNR.

Sarcogyne hypophaea (Nyl.) Arnold – Saxicolous on non-calcareous rock. RR. SNR.

Sarcogyne regularis Körb. – Saxicolous on calcareous rock. CR, DR, HR, RR. S5.

†*Sarea resinae* (Fr.) Kuntze – Resinicolous on *Picea* and *Picea glauca*. HR, RR. SNR.

Scoliciosporum chlorococcum (Stenh.) Vězda – Corticolous on *P. strobus* and on a fallen deciduous branch. CR, HR. S5.

Scoliciosporum umbrinum (Ach.) Arnold – Corticolous on *Q. rubra*. CR. S4.

Scytinium lichenoides (L.) Otálora, P.M. Jørg. & Wedin – Saxicolous. CR. S5.

Scytinium teretiusculum (Wallr.) Otálora, P.M. Jørg. & Wedin – Saxicolous. (Wong and Brodo 1992). S1S3.

†*Sphinctrina anglica* Nyl. – Lichenicolous on *P. hypotremella*. CR. S3.

†*Stenocybe pullatula* (Ach.) Stein – Corticolous on *Alnus*. CR. SU.

Thelocarpon superellum Nyl. – Terricolous. Cain 25720 (TRTC) (Wong and Brodo 1992). SNR.

Trapelia placodioides Coppins & P. James – Saxicolous. CR, HR, RR. S5

Varicellaria velata (Tuner) Schmitt & Lumbsch – Corticolous on *Fagus*. (Wong and Brodo 1992). S4.

Variolaria trachythallina (Erichsen) Lendemer, Hodgkinson & R.C. Harris – Corticolous. (Wong and Brodo 1992). S4.

Verrucaria calkinsiana Servít – Saxicolous on calcareous rock. CR, DR. S5.

Viridothelium virens (Tuck. ex E. Michener) Lücking, M.P. Nelsen & Aptroot – Corticolous on *F. grandifolia* and *Tilia*. DR. S2S3.

Xanthomendoza fallax (Hepp ex Arnold) Søchting, Kärnefelt & S. Kondr. – Corticolous on *Acer*, *A. rubrum*, *Fraxinus*, *F. americana*, and *Ulmus*. CR, DR, HR, RR. S5.

Xanthomendoza hasseana (Räsänen) Søchting, Kärnefelt & S. Kondr. – Corticolous on *Populus* snag. DR. S5.

Xanthomendoza ulophyllodes (Räsänen) Søchting, Kärnefelt & S. Kondr. – Corticolous on *A. nigrum*, a fallen deciduous tree, a snag, and on *T. occidentalis*. DR, HR, RR. S4.

Xanthoparmelia cumberlandia (Gyeln.) Hale – Saxicolous on non-calcareous rock. CR, HR, RR. S5.

Xanthoparmelia plittii (Gyeln.) Hale – Saxicolous on non-calcareous rock. HR. S4S5.

Xanthoparmelia viriduloumbrina (Gyeln.) Lendemer – Saxicolous. (Wong and Brodo 1992). CR. SU.

Xanthoria elegans (Link) Th. Fr. – Saxicolous on a non-calcareous rock. CR, DR, HR. S5.

Xanthoria parietina (L.) Th. Fr. – Corticolous on *Acer* and *P. balsamifera*; lignicolous on a *Thuja* fence rail. CR, DR, HR. SNR.

Xanthoria polycarpa (Hoffm.) Rieber – Corticolous on *Acer* and a fallen deciduous tree. CR, HR. S4.

Discussion

Our results from the four bioblitzes brings the total number of lichens and allied fungi known from the GTA to 180. This is a relatively large number of species compared to other studies in southern Ontario, such as the Arboretum at the University of Guelph (104 species; McMullin *et al.* 2014), Awenda Provincial Park (203 species; McMullin and Lendemer 2016), Copeland Forest Resources Management Area (154 species; McMullin and Lendemer 2013), and Sandbanks Provincial Park (128 species; McMullin and Lewis 2014). The major difference between these studies and the GTA bioblitzes is that they were comprehensive surveys without time restrictions. We expect to find additional species in unexamined habitats and localities in the GTA region. The GTA also differs by encompassing a much larger area than that examined by these previous studies, which could allow for a greater number of mic-

rohabitats that could be colonized by a greater number of species. However, the GTA is also affected more by air pollution, agriculture, and other industries such as historical timber harvesting that are known to have detrimental affects on lichen communities (Lesica *et al.* 1991; Henderson 2000; McMullin *et al.* 2013). Locations within the GTA that contained the greatest number of species were among the furthest from the city centre (e.g., Forks of the Credit Provincial Park and Glen Haffey Conservation Area). This pattern has been observed with lichens in four other Canadian cities (Halifax, Hamilton, Niagara, and Owen Sound; Cameron *et al.* 2007; McMullin *et al.* 2016). Despite the negative anthropogenic effects on lichen diversity, the GTA contains 37% of the 482 lichens reported in southern Ontario by Wong and Brodo (1992). This new baseline for the GTA can be used to monitor the impact of future environmental changes on lichen diversity.

Forty-two lichen species collected previously in the GTA were not collected during our study (see the Annotated Species List). We may not have examined the same microhabitats, or alternatively air pollution, habitat loss, or climate change may have caused their extirpation in the area. Targetted searches of the locations where these 42 species were collected (if they are known) would provide stronger evidence of their presence or absence in the area. Locations where species we collected are recorded to facilitate ongoing monitoring.

We discovered 13 species that are listed provincially as S1 (critically imperilled), S2 (imperilled), or S3 (vulnerable). Nine additional S1, S2, and S3 species were collected historically that we did not find. These results suggest that the GTA is ecologically important for lichens in Ontario. The most notable species we found does not have a rank because it is new to Ontario, *L. carpineae* (Figure 2; McMullin 2018). *Lecanora carpineae* is typically a western species in North America with small disjunct and scattered populations in the east, the largest of which is in the United States on the southwestern shore of Lake Superior (McMullin 2018). The only S1 ranked species that we discovered was *A. cavata*. This species may need to be reranked as it was also discovered during other recent surveys in southern Ontario (McMullin and Lewis 2014; McMullin and Lendemer 2016). Additional notable species that are rarely collected in the province and that have low ranks include *M. subargentifera* (S2S3), which has been previously collected five times (Wong and Brodo 1992; McMullin and Lewis 2013), *G. jenensis* (S2S3), which is known from four other sites (Brodo *et al.* 2013; Lewis and Brinker 2017), and *P. kairamoi* (S3 S4), which is known from three previous collections (McMullin *et al.* 2015). Although the bioblitzes were not comprehensive surveys, they revealed a surprising number of rare species as well as high overall richness.

Bioblitz projects can contribute to our understanding and, as a result the conservation, of lichens and other biota (Shorthouse 2010; Foster *et al.* 2013). The num-

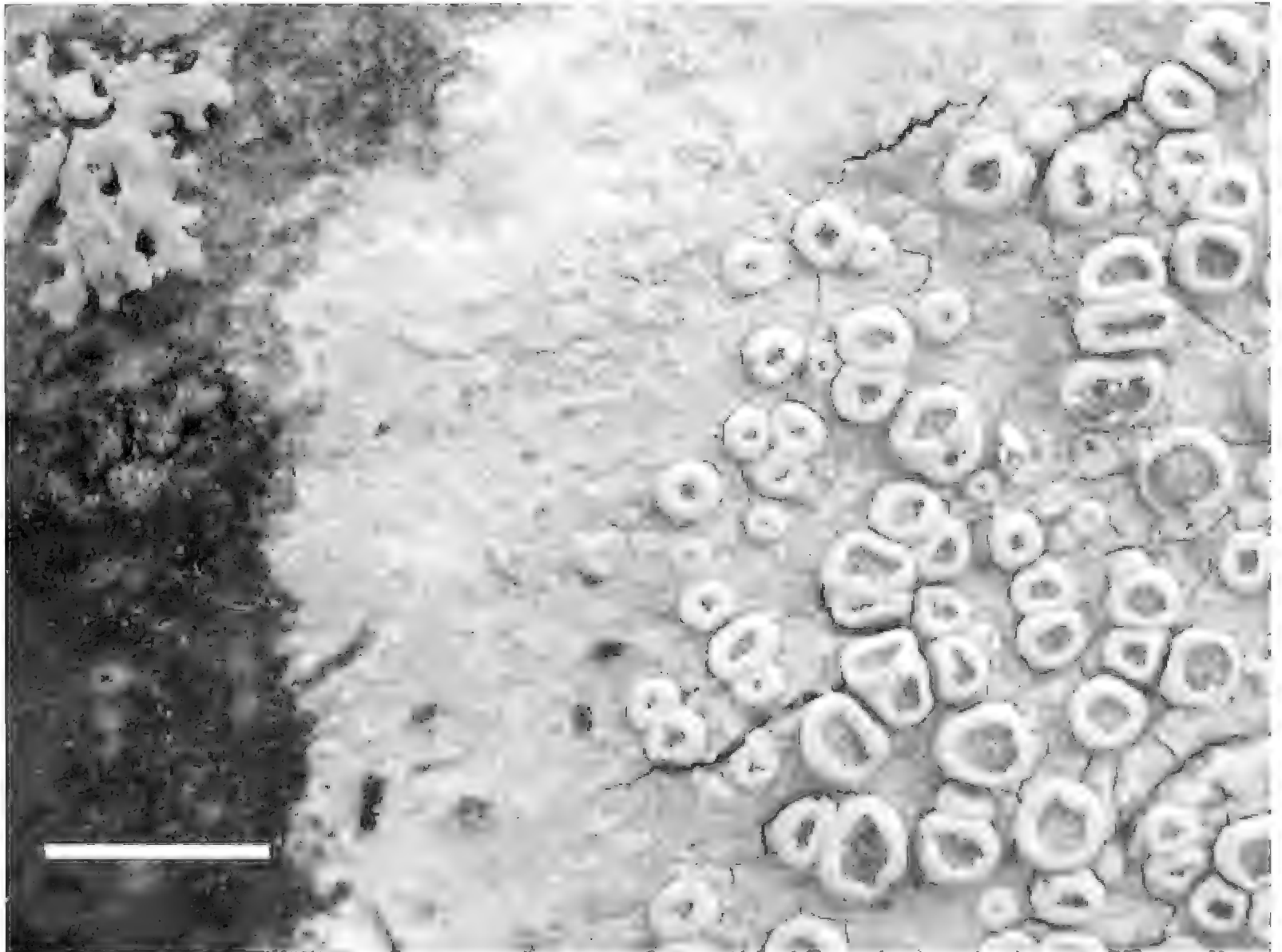


FIGURE 2. *Lecanora carpinea*, McMullin 15729 (CANL), scale = 2.1 mm. A new record for Ontario. Photo: Troy McMullin.

ber of bioblitz projects globally has increased steadily since the term was introduced in 1996, and several countries now have their own national programs (Donnelly *et al.* 2014). National Geographic partnered with many United States-based environmental organizations to complete a 10-year bioblitz project in 2016 to celebrate the 100th anniversary of the United States National Parks Service. In the final year alone, more than 125 individual events occurred, with over 13 000 species recorded by some 6000 participants (www.nationalgeographic.org/bioblitz). Bioblitz projects that include non-scientists or other members of the general public lead to an increase in peoples' biodiversity knowledge (Pollock *et al.* 2015) and often encourages learning about the natural world (Bela *et al.* 2016), particularly for children (Himschoot 2017). Bioblitz events in or near large urban areas provide opportunities to teach people about the value of the urban biodiversity where they live (Wei *et al.* 2016). Technology is also an important driver of the success of the bioblitz movement; mobile applications and taxonomic identification software allow citizen scientists to crowd-source expertise. Online tools can have a positive impact on informal science learning (Scanlon *et al.* 2014; August *et al.* 2015) and can decentralize taxonomic expertise (Gardiner and Bachman 2016). High throughput DNA

barcoding has also become more common at bioblitz events (Laforest *et al.* 2013; Telfer *et al.* 2015; Geiger *et al.* 2016) and has demonstrated that biodiversity surveys by non-experts can significantly increase overall species observations, especially when deliberately selecting diverse habitats.

Since 2012, the Ontario Bioblitz program has grown to be the largest and most robust (in terms of species documented and volunteers involved) bioblitz project in Canada. Although based in the GTA, the program has influenced province-wide action with many smaller communities adopting the program's core strategy of including taxonomic experts, citizen scientists, and general members of the public under one project delivery. The core strategy of the Ontario BioBlitz program was leveraged to propose a nation-wide bioblitz project to celebrate Canada's sesquicentennial in 2017. The project, titled BioBlitz Canada, was awarded \$750K from the federal government to launch a series of bioblitz events across the country in 2017, including five flagship events in major urban areas (e.g., Halifax, Toronto, and Vancouver), 10 science-intensive events in ecosystems with taxonomic data gaps (e.g., Kluane National Park, Yukon and Big Trout Bay along the north shore of Lake Superior, Ontario), and 20 community-level bioblitz events in every province and territory (www.bioblitz

canada.ca; Catling *et al.* 2017). The future of BioBlitz Canada rests with an advisory committee, which comprises 15 leading environmental groups and is currently facilitated by the Royal Ontario Museum.

The value of a bioblitz is multi-faceted and increasingly recognized in Canada, as it is in many other countries. The results from our study contribute to our understanding of this value. We show that, despite time restrictions, substantial scientific contributions can be made even with inconspicuous and understudied groups that are taxonomically difficult, such as lichens and allied fungi.

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SUPPLEMENTARY MATERIAL:

APPENDIX S1: Collection details of specimens examined.

Taxonomic survey of Agaricomycetes (Fungi: Basidiomycota) in Ontario tallgrass prairies determined by fruiting body and soil rDNA sampling

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Abstract

The fungal composition of North America's grasslands is poorly known, but an important area of study due to grassland conservation concerns and their close relation to agricultural lands. This study is a survey of Agaricomycetes from fifteen diverse tallgrass prairies across southwestern Ontario, determined through fruiting body surveys (above-ground) and next-generation sequencing of soil ribosomal DNA (below-ground), and compares the results of these two techniques. The most species rich taxa were the Clavariaceae, Hygrophoraceae, and Entolomataceae, each detected by both techniques, with the addition of the Sebacinaceae and Polyporaceae *sensu lato* below-ground, and Hymenogastraceae (*Hebeloma* spp.) and Mycenaceae above-ground. Many of the most abundant species belonged to these species-rich taxa and were highly abundant by either technique. The above-ground surveys found at least 73 species and the below-ground technique 238 operational taxonomic units. Although many fine-scale taxa (species and approximate families) were unique to one technique or the other (only eight genetic species were shared between both), the below-ground technique uncovered a greater breadth of higher taxa (mostly equivalent to orders), including ones undetected by the above-ground technique. A review of grassland fungi surveys around the world shows many similarities and the potential for grassland fungal conservation in North America. Given current technological advancements and grassland conservation concerns, it is prudent to further study North America's grassland fungi.

Key words: Tallgrass prairie; grassland mycota; fungal conservation; mushrooms; next-generation sequencing; basidiomycetes; survey

Introduction

Worldwide, grasslands represent the largest terrestrial biome, covering approximately 40% of the earth's land surface, and are tremendously important for the development of crop and grazing agriculture and the biodiversity of natural grassland remnants (Gibson 2009). The prairies represent the large region of grasslands in central North America. They are characterized by low or no woody plant coverage, consisting mostly of grasses and a high diversity of sparse, broadleaved herbaceous species (Sims 1988). Tallgrass prairies comprise the eastern portion of the central grasslands and have more precipitation (mesic), than the drier mixed-grass and shortgrass prairies further west (xeric; Samson and Knopf 1996). Southwestern Ontario is classified as part of the Temperate Deciduous Forest biome (Whittaker 1975; Archibold 1995), and within that as Mixed-wood Plains ecozone (Ecological Stratification Working Group 1995), so there is only a small amount of naturally occurring tallgrass prairie-oak savannah mosaic (Barcza and Lebedyk 2014). This study focussed on tallgrass prairie in southwestern Ontario, though pockets also

exist in Ontario further northwest (Quinlan 2005) and northeast (e.g., the Rice Lake plains; Catling *et al.* 1992). Prairies, particularly tallgrass, are among the most depleted and imperilled ecosystems in the world (Noss *et al.* 1995; Samson and Knopf 1996; Koper *et al.* 2010) and tallgrass prairies in Ontario are no exception (Barcza and Lebedyk 2014). Consequently, tallgrass prairie is habitat to many plant and animal species at risk (Rodger 1998; Environment Canada 2014), and perhaps unexplored fungi at risk.

The Agaricomycetes are a class of fungi (phylum Basidiomycota) that include about one-fifth of all fungal species (Kirk *et al.* 2008) and diverse morphologies of mushrooms (fruiting bodies; Hibbett *et al.* 2014). Both globally in terrestrial ecosystems and within grasslands and shrublands specifically, Agaricomycetes comprise 50% of soil fungal diversity (Tedersoo *et al.* 2014). They include the dominant saprotrophs of plant litter and other species that are pathogens and mutualists—especially those forming ectomycorrhizal relationships with plant roots (Weiss *et al.* 2004; Smith and Read 2008; Hibbett *et al.* 2014). Some species belong to more

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than one of these categories or are opportunistic (Griffith and Roderick 2008).

Illuminating the fungal composition of ecosystems by producing species lists and collections of dried specimens is an important first step for fungal conservation by providing basic information to mycologists, conservationists, and governments (Arnolds 1989a; Keizer 1993; Courtecuisse 2001; Bruns 2012). Mushroom forays are often carried out by local naturalist groups, but lists are usually not documented with specimens kept in recognized fungaria, and when they are, identifications of many taxa may be suspect if applied without attention to microscopic characters and thorough consideration of species names outside of incomplete or outdated field guides. The majority of authoritative data are found in herbaria (fungaria), which are increasingly being digitized and compiled (e.g., <http://www.MyCoPortal.org>) but still require some care with interpretation of outdated taxonomy and confirmation of identifications (Redhead 1989). Available records reveal regional and ecological gaps where specimens have not been collected.

Given the global extent of grassland cover and the importance of fungi to grassland ecosystems, it is remarkable that no estimate of a grassland mycota has been compiled. Typically, wooded ecosystems are preferred over grasslands for forays and scientific surveys (noted in Griffith and Roderick 2008; e.g., Polach 1992; Castellano *et al.* 1999; Dewsbury *et al.* 2006). Grassland mushroom fungi are best known from extensive fruiting body surveys in Europe (e.g., various grasslands in England, Wilkins and Patrick 1939; forest meadow slopes in Poland, Gumińska 1976; and coastal grasslands in the Netherlands, Arnolds 1981). There are also records from soil culturing and fruiting body surveys in Australia (Warcup 1951, 1959; Warcup and Talbot 1962, 1963, 1965), and fewer in North America (shortgrass prairie dung cultures, Wicklow and Angel 1974; alvar grasslands surveys, Mycological Society of Toronto 2005a,b; and a mixedgrass prairie survey, Hay 2013). Many studies from Europe are specific to “waxcap” grasslands, which have received special attention and mycological study due to concerns over land management changes and loss of characteristic fungi in this habitat (Rotheroe *et al.* 1996; Rotheroe 2001; Newton *et al.* 2003; Mitchel 2010; Griffith *et al.* 2013). Other studies are focussed on producing national Red Lists of species potentially at risk (e.g., the Netherlands, Arnolds 1989a). Although there is anecdotal knowledge among mycologists and naturalists of which mushrooms are found in North American grasslands (such as in field guides, e.g., Arora 1986; Barron 1999), a lack of scientific data makes study of distribution and ecology difficult or impossible (Redhead 1989). Thus, syntheses and interpretation of the available data have not been attempted.

Next-generation sequencing (NGS) represents a major advancement in high-throughput sequencing technology and, with the development of taxon-specific

DNA barcodes, has revolutionized biology (Shokrala *et al.* 2012; Lindahl *et al.* 2013; Bleidorn 2016). Communities of microorganisms can be characterized through collection of DNA sequences from environmental samples, a process termed “eDNA metabarcoding” (Taberlet *et al.* 2012). Continual growth of reference datasets such as GenBank and UNITE further facilitates more accurate and thorough classification of DNA sequences obtained through NGS, and improved primers have been developed to target specific fungal taxa based on amplification of ribosomal DNA (rDNA) regions (Asemaninejad *et al.* 2016; Taylor *et al.* 2016; De Filippis *et al.* 2017). Previously hidden fungal diversity is constantly uncovered by NGS when unclassifiable sequences are found (Hibbett *et al.* 2014; Nilsson *et al.* 2016). This has improved our understanding of the ecology and distribution of known species, particularly those that are difficult to find through culturing or fruiting body surveys. The “mycobiome” in soils and plants is often studied, albeit at taxonomic scales too coarse to uncover biodiversity at the species level (Peay *et al.* 2016). Microfungi (i.e., molds; Clarke and Christensen 1981; Maggi *et al.* 2005) and arbuscular-mycorrhizal fungi (Eom *et al.* 2000; Stover *et al.* 2012) have been surveyed in grasslands and many studies conduct microbial surveys from non-taxonomic, chemical perspectives (e.g., McKinley *et al.* 2005). Agaricomycetes in native grasslands of North America have been explored obliquely in the process of fulfilling other research objectives using NGS in tallgrass prairies of Oklahoma (Penton *et al.* 2013) and Kansas (Jumpponen *et al.* 2010; Jumpponen and Jones 2014).

The fungal taxa of a site may be uncovered using fruiting body surveys (or spores, hyphal sheaths on roots, etc.), culture-based approaches, or molecular methods (including NGS), and usually there are disparities among the results of each technique (Horton and Bruns 2001). Seeing differences among results is useful for determining limitations of any one technique and to gain a more accurate view of community composition. Results of molecular techniques have been compared with cultures of grassland or agroecosystem soil samples (Hunt *et al.* 2004; Lynch and Thorn 2006) and with fruiting body surveys of ectomycorrhizal species in treed ecosystems (Gardes and Bruns 1996; Smith *et al.* 2007; Porter *et al.* 2008; Dickie *et al.* 2009). The only mycological study we found comparing both of the above- and below-ground techniques that we use (specifically fruiting body surveys and NGS high-throughput sequencing) was of dead wood communities (Ovaskainen *et al.* 2013).

All things considered, the fungal composition of North American grasslands is a large research gap that can now readily be addressed. The objectives of this study are to survey the Agaricomycetes in selected Ontario tallgrass prairies by fruiting body and soil rDNA sampling, and to compare results of fruiting body and soil rDNA sampling techniques. These findings may yield new insights into prairie ecology and management

in conservation and restoration initiatives, will contribute to better understanding mushroom species biogeography and surveying methods, and will serve as a foundation to inform future research.

Study Area

This study sampled from fifteen different tallgrass prairie sites across southwestern Ontario, Canada (Figure 1). The sites include prairie remnants and restorations (from agricultural fields) representing a diversity of soil types and vegetative cover. We have grouped them into geographic regions and described them from west to east.

Four sites were from the Herb Gray Parkway, a major highway construction project in Windsor, Ontario. Each of the four sites underwent restorative management to remove woody and invasive plants, and had species at risk transplanted from construction zones; hence, they were labeled as “Final Restoration Sites” (FRS; Balsdon and Snyder 2015). Two of these four sites were in west Windsor with loam to loamy sand soils (FRS #23: 42.273°N, 83.069°W and FRS #32: 42.272°N, 83.070°W). The other two were in east Windsor with silty clay soils (FRS #27: 42.229°N, 82.994°W and FRS #28: 42.228°N, 82.993°W). We also sampled from two sites in the Ojibway Prairie Provincial Nature Reserve (Ojibway prairie site #1: 42.263°N, 83.071°W and Ojibway prairie site #2: 42.261°N, 83.068°W). The reserve is a large area of

tallgrass prairie and oak savannah ecosystems with silty sand to sandy soils in west Windsor near FRS #23 and FRS #32.

Five sites were located in Walpole Island First Nation (WIFN), north of Lake St. Clair, Ontario. Two sites were old agricultural fields that have revegetated after being abandoned in recent decades (WIFN sites #2 and #3) and three were chosen as representatives of high quality tallgrass prairies with minimal to no agricultural history (WIFN sites #1, #4, and #5). The soils range from silty sand to loam to silty clay. Details regarding these sites and their locations may be obtained through permission from the Nin.Da.Waab.Jig Heritage Centre.

Relatively centrally located in our survey region was the Dutton-Dunwich site (42.643°N, 81.536°W) located on a railroad line in Elgin County managed by the West Elgin Nature Club and Elgin County Stewardship Council. Despite gravel covering much of the soil and encroachment of woody vegetation, we found a diversity of quality native vegetation and pockets of undisturbed land.

On the southeastern edge of our survey area were two sites in Norfolk County, both restored tallgrass prairies with very sandy soils characteristic of the area: DeMaere prairie (42.685°N, 80.464°W), managed by the Nature Conservancy of Canada, and Mary & Peter’s prairie (42.641°N, 80.572°W) managed by private landowners. Blair Flats (43.384°N, 80.373°W) sits on the north-eastern edge of our survey area, in the

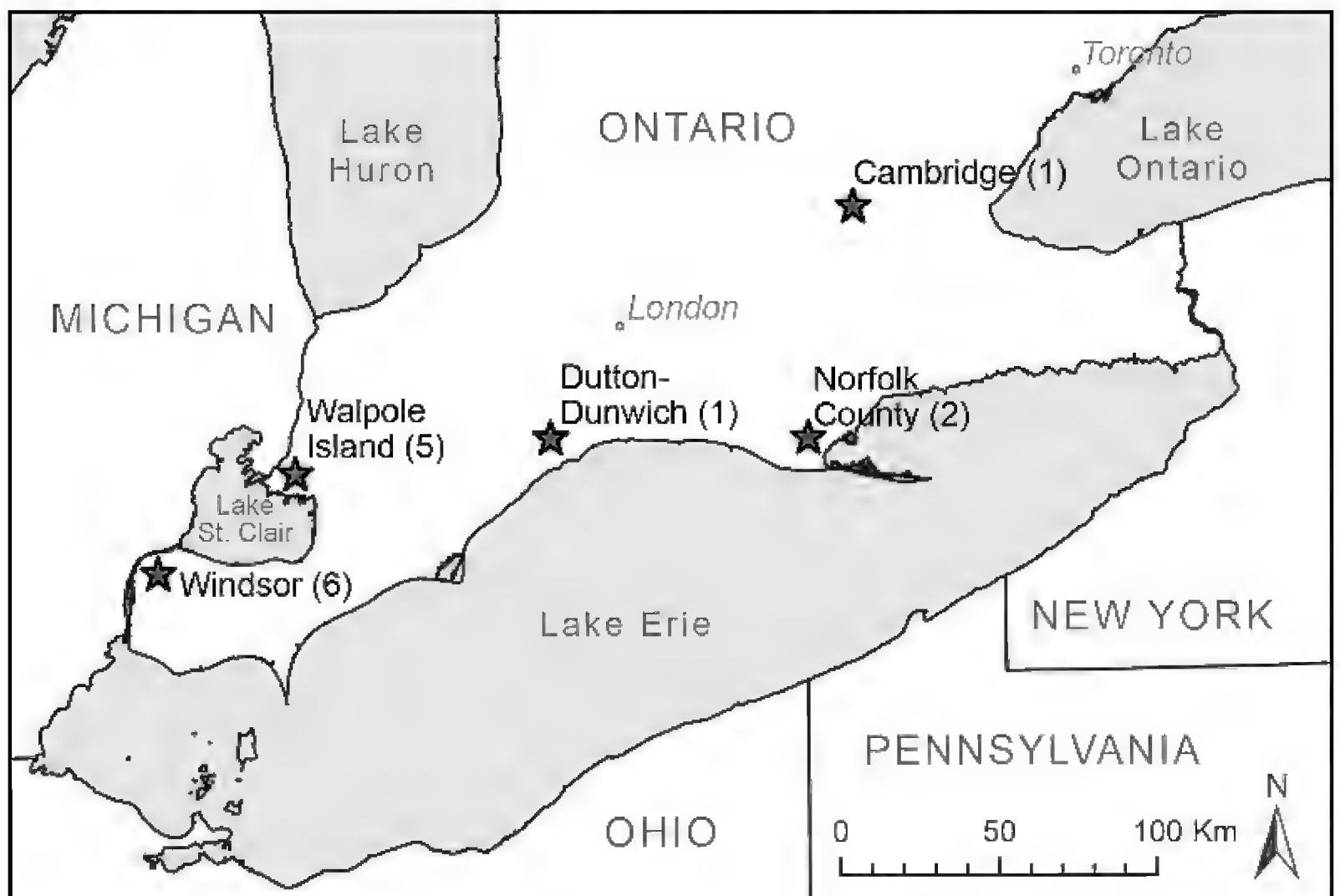


FIGURE 1. Map of 15 tallgrass prairie sites sampled across five regions in southwestern Ontario. Site abbreviations are listed in Table 1.

Township of North Dumfries near Cambridge, Ontario. It was one of our restored tallgrass prairie sites and is managed by the RARE Charitable Research Reserve. It had thick cover of native vegetation and silty clay loam soil.

Methods

Soil collection and sieving

Soil samples were collected for NGS. Six, 1 m square quadrats were sampled across each site to capture maximal variety across the landscape. Single soil cores, 20 cm deep and 2.5 cm diameter, were taken from each quadrat corner and from the quadrat centre. All five cores were mixed in one bag per quadrat. Above-ground vegetation and litter was removed from the top of each core. The soil corer was wiped clean using a cloth and 70% ethanol solution to prevent soil mixing between quadrats. Bags of soil were kept in a cooler with ice packs in the field and transferred to a −20°C freezer in the lab. Soil was collected from 2009 to 2014 at least once in June or July and once in October by investigators in previous studies (Table 1). Summer and fall samples were kept separate through the full sequencing protocol, yielding two to three timepoints of NGS data per site, though seasonal differences are not examined in the present study. Dutton-Dunwich and Mary & Peter’s prairies were not sampled for soil.

Soil subsamples of 20 g from each quadrat were mixed with 100 mL of 0.1 M (moles/L) sodium pyrophosphate for 5–10 minutes to break apart soil colloids. The mixture was poured over stacked sieves with pore sizes 1.18 mm, 0.25 mm, and 0.053 mm, and washed with deionized water. The sieve washing technique allows for the capture of plant debris, fungal hyphae, rhizomorphs, and sclerotia, while removing spores, including abundant asexual spores of ascomycetous and

zygomycetous molds (Thorn *et al.* 1996; Lynch and Thorn 2006).

Organic materials were extracted from the sieves and placed in Falcon tubes until ~5 mL was obtained for each sample. The organic materials included plant roots (and potential fungi on their surfaces) picked from the upper (coarse) sieve with forceps and dark organic matter separated from sand and silt in the middle and lower (fine) sieves, collected with a spatula and broad tip pipette, respectively. Sieves and collecting tools were thoroughly rinsed with deionized water and cleaned using 70% ethanol between each sample.

Soil DNA extraction, PCR procedures, and submission for NGS

To ensure cell wall lysis prior to DNA extraction, soil organic matter was lyophilized using a Virtis Bench Top 3.5 L Freeze Dryer (SP Scientific, Stone Ridge, New York, USA) and ground to a floury texture using liquid nitrogen in a sterile mortar and pestle for each sample. DNA extraction was carried out using a Soil Microbe DNA MicroPrep™ kit (Zymo Research, Irvine, California, USA) following standard protocols. This involved bead-beating samples using a Fast-Prep™ FP210 machine (Bio101, Qiogene, Inc., Carlsbad, California, USA) set at a speed of 4.0 for 30 seconds. The concentration of eluted DNA was measured using a Nanodrop2000 Spectrophotometer (Thermo-Fisher, Mississauga, Ontario, Canada).

PCR was carried out by combining solutions to a total of 25 µL in microtubes: 3.0 to 5.0 µL molecular grade water (remaining difference), 3 µL each of forward and reverse primers, 12.5 µL ToughMix (Quanta Biosciences, Beverly, Massachusetts, USA), 1.0 to 3.0 µL template DNA (at ~20 ng/µL), and 0.5 µL loading dye. The primers used were LSU200-F and LSU481-R (AACKGCGAGTGAAGMGGGA and TCTTTCCCT-

TABLE 1. Site visits for soil and/or fruiting bodies at 15 tallgrass prairie sites across southwestern Ontario. Footnotes identify principal investigators associated with sampling.

Site	Abbreviation	Soil sampling	Fructing body surveys
FRS #23	HA	July and October 2014 [‡]	June, July and October 2015 [§]
FRS #32	HB	July and October 2014 [‡]	June, July and October 2015 [§]
Ojibway prairie site #1	OA	July and October 2014 [‡]	June, July and October 2015 [§]
Ojibway prairie site #2	OB	July and October 2014 [‡]	June, July and October 2015 [§]
FRS #27	HC	July and October 2014 [‡]	June, July and October 2015 [§]
FRS #28	HD	July and October 2014 [‡]	June, July and October 2015 [§]
Walpole Site #1	WA	June and October 2009 [*] , October 2014 [‡]	October 2014, July and October 2015 [§]
Walpole Site #2	WB	June and October 2009 [*] , October 2014 [‡]	October 2014, July and October 2015 [§]
Walpole Site #3	WC	June and October 2009 [*]	not sampled
Walpole Site #4	WD	June and October 2009 [*] , October 2014 [‡]	October 2014, July and October 2015 [§]
Walpole Site #5	WE	June and October 2009 [*] , October 2014 [‡]	October 2014, July and October 2015 [§]
Dutton-Dunwich	DD	not sampled	June and October 2015 [§]
Mary & Peter’s prairie	MP	not sampled	June and October 2015 [§]
DeMaere prairie	DM	July and October 2014 [†]	October 2014, July and October 2015 [§]
Blair flats	BF	July and October 2014 [‡]	October 2014, August and October 2015 [§]

*Chokroborty-Hoque (2011).

†Catomeris (2015).

‡Allan (2017).

§The present study.

CACGGTACTTG, respectively), which target ~250 nucleotide bases at the D1 large subunit (LSU) region of ribosomal DNA (Asemaninejad *et al.* 2016). Barcodes were included with forward and reverse primers to discriminate among site visits. Soil templates were PCR-amplified using a Biometra T1 Thermocycler (Montreal Biotech, Dorval, Quebec, Canada) programmed as follows: 94°C 2 min, 30 cycles of 94°C 30 sec, 60°C 30 sec, 72°C 18 sec, and holding at 4°C after cycling. PCR products were checked for successful amplification by gel electrophoresis using 1.0% (w/v) agar-agar gels in 1× TAE buffer with 0.5 µg/mL ethidium bromide. PCR products from each of the six quadrats were pooled to one tube per site visit, lyophilized, and rehydrated before being submitted for paired-end Illumina MiSeq high-throughput sequencing using a 2×300 kit. Sequencing was conducted by the London Regional Genomics Centre (Robarts Research Institute, London, Ontario, Canada).

NGS data processing and taxonomic annotation

Raw soil sequence data following Illumina MiSeq were submitted to the European Nucleotide Archive (ENA) by sites, under project accession number PRJEB19932. The raw data were processed using a pipeline developed by Greg Gloor, Biochemistry, University of Western Ontario, London, Ontario, Canada which is available on GitHub (http://www.github.com/ggloor/miseq_bin/tree/Jean). PANDAseq overlapped forward and reverse sequence reads with a minimum overlap of 30 nucleotides (Andre *et al.* 2012). Sequence data from three Illumina MiSeq runs were processed separately until this stage when they were combined, using the script `workflow_combined_runs.sh` from the aforementioned GitHub. A number of programs are used in this workflow. UCLUST was used to create identical sequence unit clusters (ISUs, 100% similarity), then UCHIME was used to find and remove chimeric sequences (Edgar *et al.* 2011). This removed 22 600 possibly chimeric sequences from the 529 300 unique sequences. UCLUST was then used to further cluster ISUs into operational taxonomic units (OTUs, 97% similarity) with a most common, centroid seed OTU sequence (Edgar 2010). A 99% similarity cutoff has been used to delimit yeast species OTUs from sequences of the D1-D2 LSU(25S) region of rRNA (Peterson and Kurtzman 1991), but we chose 97% because our amplicons were from only the most variable (D1) part of this region. Our sequence clustering produced 14 300 OTUs. The read counts were attached to OTUs, using a 0.1% cutoff in any sample.

To capture Agaricomycete OTUs only, sequences were filtered using the Ribosomal Database Project (sequence classifier, gene database: fungal LSU training set 11; Wang *et al.* 2007) and a neighbour-joining tree to produce an Agaricomycete clade after alignment using MUSCLE (Edgar 2004) in MEGA6 (Tamura *et al.* 2013). Agaricomycete OTUs were annotated to a finer scale by querying through NCBI's GenBank database using the Basic Local Alignment Search Tool for

nucleotide sequences (blastn) to find matches. Species-level names were applied only when query cover and percent identity were both greater than 97% and no competing species names were retrieved within this range. Filtering by taxonomic identity for Agaricomycetes left 281 OTUs. These Agaricomycete OTU sequences were submitted to GenBank under accession numbers KY353514–KY353794. OTUs were sorted into coarser taxonomic groups as minor (ca. family) and major (ca. order) clades based on their assigned taxonomic annotation and placement in a neighbour-joining tree.

Fruiting body field surveys and sequencing of specimens

Fruiting body collection allowed us to sample a larger area than soil coring and provided us with voucher specimens as tangible records for morphological and sequence-assisted identifications. Surveys were conducted at each site in a wandering design covering on average 2.2 ha and ranging from ~0.2 to 10 ha. A global positioning system (GPS) receiver was used to ensure soil sampling quadrats were surveyed and to evenly search remaining ground of each site. Fruiting bodies were counted, genetic individual counts estimated from clusters of fruiting bodies, and a voucher specimen collected for each morphospecies (conservatively estimated in the field). Each voucher was documented with a specimen code, photos, GPS coordinates, and habitat notes, and was preserved using a food dehydrator before being stored in a paper herbarium packet. We conducted fruiting body surveys two to three times for each site on dates ranging from October 2014 to 2015 (Table 1). WIFN site #3 was not sampled for fruiting bodies. Dried specimens were deposited at the University of Western Ontario herbarium (UWO) and associated photos and data (including which identification resources were consulted) are available online (http://www.mushroomobserver.org/species_list/show_species_list/652).

Genomic DNA was extracted from mushroom specimens using the GeneJET Plant Genomic DNA Purification Mini Kit (Thermo Fisher Scientific Inc., Mississauga, Ontario, Canada), starting with bead beating in a FastPrep™ FP120 machine (Bio101, Qiagen Inc., Carlsbad, California, USA) set at 4.0 for 30 seconds. The concentration of eluted DNA was measured using a Nanodrop2000 Spectrophotometer. PCR was carried out by combining solutions to a total of 25 µL in microtubes: 9.0 to 9.5 µL molecular water (remaining difference), 1.25 each of forward and reverse primers, 12.5 FroggaMix (FroggaBio, Toronto, Ontario, Canada), and finally 0.5 to 1.0 µL template DNA (at ~20 ng/µL). We used the primers ITS8F and LR3-mod (AGTCGTAACAAGGTTTCCGTAGGTG and GGTCCGTGTTTCAAGACGGG, respectively), which cover ~1300 bases, including partial SSU, complete ITS1, 5.8S, and ITS2, and partial LSU (Vilgalys and Hester 1990; Dentinger *et al.* 2010). This overlaps the region amplified by LSU200-F and LSU481-R for the soil samples

(which is important for our later analyses comparing sequences between the above- and below-ground techniques). Fruiting body templates were PCR-amplified using a MWG Biotech Primus96 (Huntsville, Alabama, USA) thermocycler programmed as follows: 94°C 1 min, 30 cycles of 94°C 30 sec, 58°C 30 sec, 72°C 1 min 30 sec, an extension time of 72°C for 7 min, and finally holding at 4°C. Successful PCR products were cleaned using the EZ-10 Spin Column PCR Products Purification Kit (Bio Basic Canada Inc., Markham, Ontario, Canada) and submitted for Sanger sequencing (Sanger *et al.* 1977). Each PCR sample was submitted four separate times with different primers to cover the entire amplified length: ITS8F, LS1R-mod (CTTAAG TTCAGCGGGTAGTCC), LS1-mod (GGACTACCC GCTGAACTTAAG), and LR3-mod (Vilgalys and Hester 1990; Hausner *et al.* 1993; Dentinger *et al.* 2010). Sequencing was conducted by the London Regional Genomics Centre (Robarts Research Institute, London, Ontario, Canada).

Fruiting body sequences were assembled and checked for errors using Geneious 8.0.5 (Kearse *et al.* 2012). Assembled sequences were queried through GenBank to find matches that might help to inform identification of specimens. Fruiting bodies were identified using taxonomic keys, involving navigating through indicative macro- and micro-scopic features, chemical tests, and ecological context. Sequences were deposited in GenBank under accession numbers KX215469–KX215471 and KY706152–KY706198 (Supplementary Data Sheets A and E; Hay *et al.* 2018).

Statistical analyses

To compare soil rDNA sequencing and fruiting body surveys, data from WIFN site #3, Dutton-Dunwich prairie, and Mary & Peter’s prairie were excluded because these sites were not sampled with both techniques. To ensure soil data were equally weighted across sites, two additional quadrats in DeMaere prairie were excluded to maintain consistency of six quadrats per site, and Walpole Island site samples from October 2009 were excluded to maintain two samples per site from each season (early summer and fall).

Average relative abundances of OTUs were calculated by dividing read values by the sum reads for each site visit (column) and averaging for each OTU (row) across all site visits. Shared genetic species were found by bringing OTU and fruiting body sequences into MEGA 6, aligning with MUSCLE, trimming to OTU length (the limiting factor), then using Microsoft Excel 2013 (version 15.0.4737.1001, Microsoft Corporation, Redmond, Washington, USA) to highlight duplicate sequences. Venn diagrams illustrating degrees of overlap at different taxonomic scales were created using the venneuler package (Wilkinson 2011) in RStudio (RStudio Team 2016). A map of site regions was produced using QGIS 2.18.15 (QGIS Development Team 2017) and open source boundary data (Statistics Canada 2011; United States Census Bureau 2016).

Results

Fruiting body survey totals and common taxa

From the 14 sites surveyed two to three times for fruiting bodies, at least 73 different species were found across 45 genera, of which 57 were identified to species level. Sequences were obtained from 50 collections representing at least 40 different species. The number of species found ranged from zero to 22, and was on average nine species per site (Supplementary Data Sheets A and B; Hay *et al.* 2018).

The most abundant species by counts of estimated genetic individuals (clusters of similar fruiting bodies) were *Entoloma sericeum* (Bull.) Quél. (“silky pinkgill”; note: because there are no standard common names for fungal species, including mushrooms, common names when they exist are included in quotation marks upon first occurrences), which was found covering a large proportion of the ground at Blair Flats during a fall survey, unidentified white *Clavaria* species, *Cotylidia undulata* (Fr.) P. Karst. (“stalked rosette”) found only at DeMaere prairie, and unidentified *Clitopilus* and *Mycena* (*sensu lato*, white) species (Table 2). The species occurring across the most (four) sites were *Entoloma* subgenus *Leptonia* (diaphanous, umbilicate), *Marasmiellus* sp., and *Vascellum curtisii* (Berk.) Kreisel (Table 2). The most species rich minor clades (ca. families) were the Entolomataceae, Hygrophoraceae, Hymenogastraceae (mostly *Hebeloma* spp.), Clavariaceae, and Mycenaceae, with 17 to five species each (Figure 2).

Soil rDNA sampling totals and common taxa

After quality filtering, removing rare OTUs, and removing sequences of non-agarics, 1 194 767 reads of 281 OTUs from 30 samples (site visits) remained, an average of 39 826 reads and 30 OTUs per sample (Supplementary Data Sheet D; Hay *et al.* 2018). Removal

TABLE 2. The 17 most abundant fruiting body species (four or more individuals), as measured by the number of individuals, estimated from groups or clusters of fruiting bodies.

Species	Individuals	Sites
<i>Entoloma sericeum</i>	17	2
<i>Clavaria</i> sp. (white)	12	2
<i>Cotylidia undulata</i>	12	1
<i>Clitopilus</i> sp.	10	3
<i>Mycena</i> sp. (<i>sensu lato</i> , white)	10	3
<i>Entoloma</i> subgenus <i>Leptonia</i> (diaphanous, umbilicate)	9	4
<i>Marasmiellus</i> sp.	9	4
<i>Vascellum curtisii</i>	9	4
<i>Hygrocybe conica</i> (group)	7	3
<i>Mutinus</i> cf. <i>elegans</i>	6	3
<i>Tubaria furfuracea</i>	6	3
<i>Astraeus hygrometricus</i>	6	1
<i>Entoloma incanum</i>	4	2
<i>Hebeloma</i> cf. <i>sporadicum</i>	4	2
<i>Psathyrella ammophila</i>	4	2
<i>Hebeloma</i> cf. <i>dunense</i>	4	1
<i>Omphalina pyxidata</i>	4	1

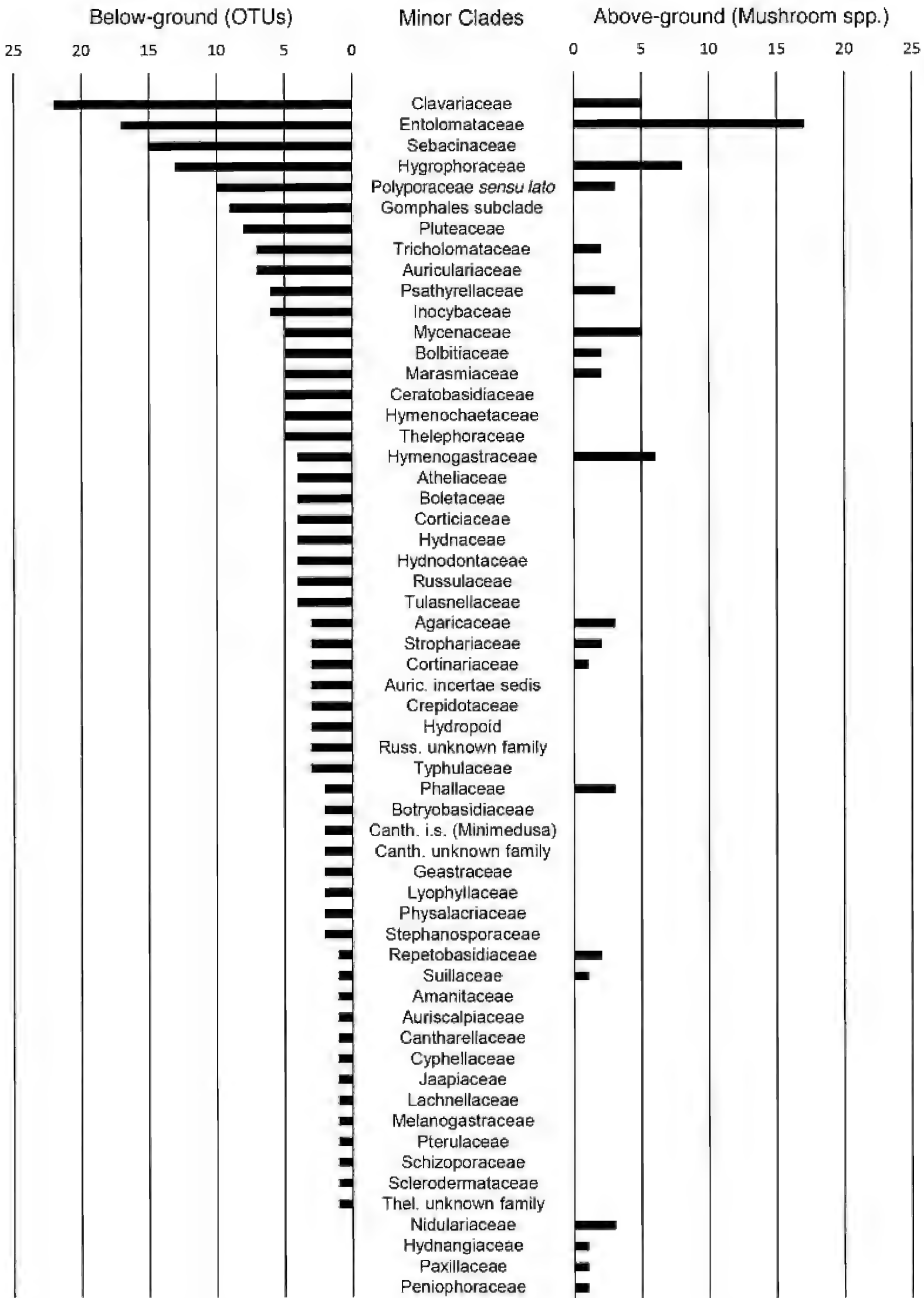


FIGURE 2. Richness of operational taxonomic units (OTUs) and species within minor clades (ca. family level), comparing results of soil rDNA NGS (“below-ground”) with fruiting body (“above-ground”) surveys. Richness here is a function of the composition of all sites, taxonomic diversity in each clade, and detection ability of each technique.

of extraneous sampling data reduced the number of Agaricomycete OTUs from 281 to 238 OTUs which were used in the analyses following. Six OTUs remained unknown, because query results represented diverse taxa and OTU phylogram branches showed low bootstrap values. These OTUs were included in species-level analyses but were not counted as a unique minor or major clade. Excluding the clades for the unknowns (one minor and one major), diversity spanned 55 minor clades and 19 major clades (Supplementary Data Sheet C; Hay *et al.* 2018).

The OTUs from soil rDNA sampling with highest relative read abundances were *Minimedusa polyspora* (Hotson) Weresub & P.M. LeClair and *Ceratobasidiaceae* sp. 1 that do not produce fruiting bodies visible to the naked eye, and *Hygrocybe conica* (“witch’s hat”) group sp. 3 and *Mutinus elegans* (Mont.) Fisch. (“elegant stinkhorn”) that do (Table 3). The OTUs occurring across the most sites were *M. polyspora*, *Fomitopsidaceae* sp., *Entoloma* sp. 3, *Gomphales* sp. 3, and *Lycophyllaceae* sp. 2 (Table 3; Supplementary Data Sheet D; Hay *et al.* 2018). The most OTU rich minor clades (ca. families) were the *Clavariaceae*, *Entolomataceae*, *Sebacinaceae*, *Hygrophoraceae*, and *Polyporaceae sensu lato*, with 22 to 10 OTUs each (Figure 2).

Collective results and comparison between above- and below-ground techniques

Across both sampling techniques, the most species and OTU rich clades found were the *Clavariaceae*, *Hygrophoraceae*, and *Entolomataceae* (Figure 2). Many minor clades were only found using the below-ground technique (soil rDNA NGS), not by above-ground sampling (fruiting body surveys), whereas relatively few were unique to above-ground sampling. Most minor clades unique to the below-ground sampling technique seldom or never produce conspicuous fruiting bodies (e.g., *Sebacinaceae*) or may represent uncommon species that were overlooked during sampling. Minor clades unique to the above-ground sampling technique are either mycorrhizal incidentals (*Hydnangiaceae* and *Paxillaceae*) or saprobes apparently limited to colonization of litter above the soil surface (*Nidulariaceae* and *Peniophoraceae*). Other taxa not exclusive to one technique were still found disproportionately by one or the other. For example, in the *Clavariaceae* 22 OTUs were found below- and only five above-ground. In con-

TABLE 3. The 15 most abundant soil rDNA operational taxonomic units (OTUs), as measured by average relative abundance (average relative abundance of OTU in each sample i.e., site visit, averaged across all samples).

OTU	Average relative abundance	Sites
<i>Minimedusa polyspora</i>	0.0978	12
<i>Ceratobasidiaceae</i> sp. 1	0.0393	4
<i>Hygrocybe conica</i> group sp. 3	0.0387	4
<i>Mutinus elegans</i>	0.0385	4
<i>Gomphales</i> sp. 3	0.0333	10
<i>Hygrocybe conica</i> group sp. 2	0.0318	7
<i>Russulales</i> sp. 1	0.0313	5
<i>Sebacinaceae</i> sp. 2	0.0248	5
<i>Tricholomataceae</i> sp. 3	0.0227	6
<i>Mycena epipterygia</i> sp. 1	0.0223	6
<i>Entoloma</i> sp. 3	0.0201	10
<i>Fomitopsidaceae</i> sp.	0.0185	10
<i>Hymenogastraceae</i> sp.	0.0181	8
<i>Hypochnicium</i> sp.	0.0179	4
<i>Hypholoma</i> sp.	0.0163	3

trast 17 OTUs or species of *Entolomataceae* were found in each of above- and below-ground techniques.

Shared species and degrees of overlap at different taxonomic scales

There were eight species detected by both the above and below-ground techniques that had identical sequences (“shared species”; Table 4). Some of these shared species were found by both methods at the same site (e.g., *C. undulata*), by only one technique or the other across different sites (e.g., *Clavaria* cf. *fragilis* Holmsk. [“white spindles”]), or a combination of these two scenarios (e.g., *V. curtisii*). Several species seem to correspond between techniques (Tables 2 and 3), but are unconfirmed: *Mycena epipterygia* (Scop.) Gray sp. 1 OTU with the abundant *Mycena* sp. (*sensu lato*, white) fruiting bodies for which sequencing failed, the *Hymenogastraceae* sp. OTU with *Hebeloma* spp. fruiting bodies, and species with identical names between both tables: the *H. conica* group spp., *M. elegans*, and species of *Entoloma*.

The degree of overlap between fruiting body and soil rDNA sampling depends on the taxonomic scale in consideration, as seen in Venn diagrams (Figure 3). At the finest scale of genetic species only eight species were

TABLE 4. Detection of shared species (identical sequences) across sites via fruiting body surveys (above-ground – A), rDNA soil sampling (below-ground – B), or both (AB). Site abbreviations as in Table 1.

Species	HA	HB	OA	OB	HC	HD	WA	WB	WD	WE	DM	BF
<i>Arrhenia</i> cf. <i>acerosa</i>	A									A	B	
<i>Clavaria</i> cf. <i>acuta</i>			B	B	B			A	B			
<i>Clavaria</i> cf. <i>fragilis</i>		B							A			
<i>Cotylidia undulata</i>											AB	
<i>Entoloma incanum</i>		B	B	B					AB	A		
<i>Entoloma</i> cf. <i>tubaeforme</i>	AB	A								A		
<i>Hygrocybe conica</i> group	B	B	B	B		B	B	A		AB		
<i>Vascellum curtisii</i>	B			B			A		AB	AB		

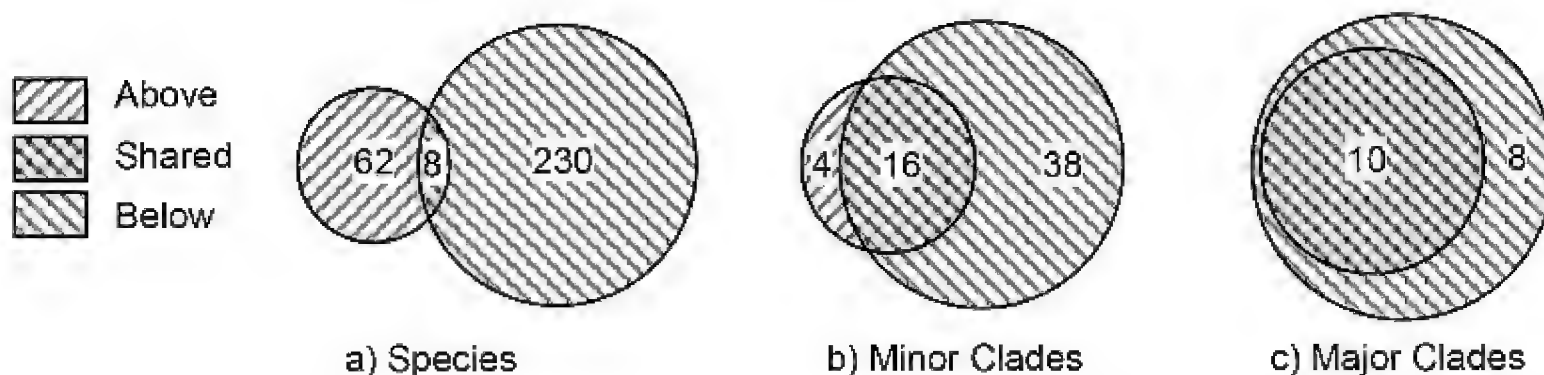


FIGURE 3. Area-proportional Venn diagrams comparing below-ground (soil rDNA high throughput sequencing) and above-ground (fruiting body survey) richness at three taxonomic scales: a. genetic species (identical sequences of operational taxonomic units with fruiting body sequences), b. minor clades (ca. family), and c. major clades (ca. order).

shared, representing 11% of above-ground and 3% below-ground diversity (Figure 3a). At the minor clade level (ca. family) 16 minor clades were shared, representing 76% of above-ground minor clades and 30% of those below-ground (Figure 3b). At the major clade level (ca. order) all 10 major clades found above-ground were also found below-ground, representing 56% of below-ground major clades (Figure 3c). This shows that even at a coarse taxonomic scale (major clades), fruiting body surveys failed to detect the full range of diversity in the soil-inhabiting Agaricomycetes.

Discussion

A grassland mycota

Combining our above-ground survey data with selected grassland studies from around the world (Wilkins and Patrick 1939; Warcup 1951, 1959; Warcup and Talbot 1962, 1963, 1965; Wicklow and Angel 1974; Gumińska 1976; Arnolds 1981; Mycological Society of Toronto 2005a,b; Hay 2013; Detheridge *et al.* 2018) we were able to compile a grassland mycota and identify where tallgrass prairies fit in this context. Almost 500 species of Agaricomycetes were reported among the eight groups of studies examined (including ours). One fifth of species were reported in two or more groups of studies. The most common species were *Agaricus campestris* L. (“meadow mushroom”), *Hygrocybe conica* (Schaeff.) P. Kumm. (“witch’s hat”), *H. miniata* (Fr.) P. Kumm. (“vermillion waxcap”), *Cuphophyllus virgineus* (Wulfen) Kovalenko (“snowy waxcap”), *E. sericeum*, and *Lycoperdon perlatum* Pers. (“gem-studded puffball”). The most commonly reported genera were *Agaricus*, *Bovista*, *Coprinopsis*, *Hygrocybe*, *Lycoperdon*, and *Parasola*, and the genus with the most reported species was, by far, *Entoloma* (64 species). All these species and genera were found in our study except for *L. perlatum*. Although we initially identified several puffball specimens as *L. perlatum*, we corrected our identification to *V. curtisii* after microscopic spore inspection. *Entoloma* was also our most speciose genus at 15 species.

We found at least six gasteroid species and they were not limited to sites with any specific conditions or to any one region. Common genera from our study

and others in our review include small puffballs from *Bovista*, *Lycoperdon*, and *Vascellum*; large puffballs represented by *Calvatia* spp. and *Mycenastrum corium* (Guers.) Desv. (“leathery puffball”; Mycological Society of Toronto 2005b); and the stinkhorns *Phallus* or *Mutinus*. Gasteroid and secotoid species are typical in hot dry environments (e.g., Gabel and Gabel 2011; Tomaszewska *et al.* 2015). The secotoid species *Chlorophyllum agaricoides* (Czern.) Vellinga (“puffball agaric”), *Battarrea phalloides* (Dicks.) Pers. (“scaley-stalked puffball”), and others were found in arid Saskatchewan mixedgrass prairie (Hay 2013), but no secotoid taxa were encountered in our surveys. We suspect that Ontario tallgrass prairies, but perhaps not all tallgrass prairies, are too moist for them.

Most grassland surveys, including our own, encountered species associated with living or dead trees and shrubs. Wood decomposers may appear when deadfall is available or on litter with enough lignin content (e.g., *Galerina* spp. from Arnolds [1981]; *Trametes* and *Peniophora* spp. from the present study and by Warcup and Talbot [1963]; *Tubaria* spp. from multiple studies). However, wood decomposing fungi have been found in subsurface soil (Goos 1960; Lynch and Thorn 2006), so our Polyporaceae *sensu lato* OTUs may represent a natural component of tallgrass prairie soils. The rarely reported (and perhaps of conservation importance) *Polyporus cryptopus* Ellis & Barthol. (“prairie polypore”) is an exception to its genus, attached to grass roots rather than wood, and is unique to North American grasslands. There are several collections from the central USA states (e.g., Cripps 2011) and fewer from the Canadian prairies (Saskatchewan: Hay 2013; Ontario: previously collected from WIFN Site #4 – RGT 090616/sn, UWO). It has been suggested to be a synonym of the Eurasian species now known as *Picipes rhizophilus* (Pat.) J.L. Zhou & B.K. Cui (Zhou *et al.* 2016) but studies of type material of both are required for confirmation. Ectomycorrhizal species (associated with the roots of living trees or shrubs) are also reported in grassland surveys, usually only when trees are nearby. This includes species of *Hebeloma*, *Cortinarius*, *Russula*, and *Suillus* from the present study, and *Hebeloma* spp. reported in other studies (Wilkins and Patrick 1939; Arnolds 1982). However, some ectomy-

corrhizal fungi partner with small perennial plants such as *Lechea mucronata* Raf. [Cistaceae], recorded as *Lechea villosa* Ell. from a grassland site in the same county as our sandy sites (DeMaere prairie and Mary & Peter's prairie; Malloch and Thorn 1985). The Sebacinaceae are best known for being included in mycorrhizal partnerships with a wide diversity of plants (Weiss *et al.* 2004) but may also be endophytes (Weiss *et al.* 2011) or of unresolved ecologies (Tedersoo *et al.* 2010). Many Sebacinaceae OTUs were detected in the below-ground portion of our study and a similar study from agricultural soils in Michigan, USA (Wong 2012). Above-ground fruiting bodies are rarely reported, probably due to their inconspicuous corticioid nature, although species of *Sebacina* were cultured in studies by Warcup and Talbot (1962, 1965). Many endophytic and parasitic taxa produce inconspicuous fruiting bodies and so are more easily detected by culturing or sequencing, as demonstrated with the Sebacinaceae in our study and review.

Decomposers of above-ground plant litter are commonly reported from fruiting body surveys when methods include litter searches. The most commonly reported genera are *Parasola* and *Mycena* spp. (though some of the species may grow from the soil, not litter), and appearing in fewer studies *Cyathus*, *Nidula*, and *Marasmiellus* spp. Our study found all of these taxa, showing the importance of including careful litter examination when conducting complete surveys. Coprophilous species are often conspicuous from sites actively managed by large grazing mammals (e.g., sheep in Wilkins and Patrick [1939]; cattle in Wicklow and Angel [1974]; American Bison [*Bison bison*] in Hay [2013]), but most grasslands receive some dung from wildlife (e.g., Pronghorn Antelope [*Antilocapra americana*], rabbits, and voles). Commonly reported taxa from our review were *Coprinopsis* spp. (especially *Coprinopsis nivea* (Pers.) Redhead, Vilgalys & Moncalvo ["snowy inkcap mushroom"]), *Panaeolus* spp. (esp. *Panaeolus papilionaceus* (Bull.) Qué. ["petticoat mottlegill"]), *Protostropharia semiglobata* (Batsch) Redhead, Moncalvo & Vilgalys ("dung roundhead"), and *Deconica coprophila* (Bull.) P. Karst. ("dung-loving *Psilocybe*"). Our study included no sites with large grazing mammals and no fruiting bodies were observed on any small dung examined, so all the coprophilous fungi listed here were noticeably absent from our study.

Terrestrial saprobic species in grasslands cover a wide array of taxonomic groups. *Agaricus campestris* was present across more studies than any other species, with other agaricoid members of the Agaricaceae reported moderately frequently (genera *Chlorophllum*, *Macrolepiota*, and *Lepiota*) and other *Agaricus* spp. less frequently. From other families, *Marasmius oreades* (Bolton) Fr. ("fairy ring mushroom") and *Clitocybe* spp. were commonly reported, *Melanoleuca* spp. moderately, and *Volvariella* sp. and *Volvopluteus gloiocephalus* (DC.) Vizzini, Contu & Justo ("rose-gilled grisette")

less frequently. Aside from *A. campestris* and *Clitocybe dealbata* (Sowerby) Gillet ("ivory funnel") found at one of our sites, we did not find any of these taxa in our tallgrass prairie surveys. Many other terrestrial saprobic taxa are considered nutrient-loving due to their abundance in sites supplemented with dung or artificial fertilizers, specifically species of the Psathyrellaceae (genera: *Coprinellus*, *Coprinopsis*, *Panaeolus*, *Parasola*, *Psathyrella*), Strophariaceae (genera: *Agrocybe*, *Deconica*, *Stropharia*), and genera from other families: *Conocybe*, *Marasmius*, and *Psilocybe* (Arnolds 1988, 1989b; Mycological Society of Toronto 2005b). We encountered few of these nutrient-loving species in our tallgrass prairie surveys (*Coprinopsis lagopus* (Fr.) Redhead, Vilgalys & Moncalvo ["harefoot inkcap"], *Parasola* cf. *conopilus* (Fr.) Örstadius & E. Larss. ["conical brittlestem"], and *Stropharia coronilla* (Bull.) ["garland *Stropharia*"]), suggesting Ontario tallgrass prairies are naturally relatively nutrient-poor.

We found more Clavariaceae, *Hygrocybe*, and *Entoloma* (CHE) species in Ontario tallgrass prairies than the other terrestrial surveys of North American grasslands (Mycological Society of Toronto 2005a,b; Hay 2013). In contrast to the terrestrial saprobic and nutrient-loving taxa, these fungi prefer nutrient-poor grasslands, such as the unimproved waxcap grasslands of Europe (Arnolds 1989a; Rotheroe *et al.* 1996; Detheridge *et al.* 2018). Most non-lignicolous Clavariaceae species are believed to be biotrophic (Birkebak *et al.* 2013) and grassland *Hygrocybe* species are biotrophic with grasses (Griffith *et al.* 2014). In addition, these two taxa have correlated diversity across grassland sites, but not with *Entoloma* (Newton *et al.* 2003). Most species of *Entoloma* are believed to be saprobic (Noordeloos 2004) with few known parasitic (Agerer and Waller 1993; Czederpiltz *et al.* 2001) or mycorrhizal (Kobayashi and Yamada 2003; Rinaldi *et al.* 2008) exceptions. We suggest grassland *Entoloma* species may also be biotrophic in some way, because even *Entoloma* species growing on dead wood are not readily cultured (R.G.T. pers. obs.). Detheridge *et al.* (2018) consider the CHE taxa biotrophic and group them as one of five fungal ecological functional groups. The abundance of these taxa suggests similar ecological dynamics are at play between tallgrass prairies and European waxcap grasslands, in contrast to drier, nutrient-rich, or agriculturally improved grasslands. Besides the CHE taxa, we found *Arrhenia* cf. *acerosa* (Fr.) Kühner ("moss oysterling"), which is associated with ground-dwelling mosses (usually in open grassy areas of woods but apparently also in grasslands, e.g., forest meadows; Gumińska 1976). Investigations are under way to determine if lowland specimens of *A. cf. acerosa* are distinct from arctoalpine ones originally described by Fries (1821; Voitek 2017).

Waxcap grassland surveys focus on surveying from five taxonomic groups to assess grassland quality: Clavariaceae (C) ("coral fungi"), *Hygrocybe* (H) ("wax-

caps”), *Entoloma* (E) (“pinkgills”), Geoglossaceae (G [“earth tongues”], Ascomycota; not included in our survey), and *Dermoloma* (D; not detected in our survey; Rotheroe *et al.* 1996). Ratios between taxa have been examined to compare community composition among grasslands (Newton *et al.* 2003) though the initial use of this system was to highlight sites with high conservation value by uniformly sampling across sites on a national or international scale (Rotheroe *et al.* 1996). In a comparison of recent surveys of Welsh grasslands, Griffith *et al.* (2013) found the number of species within each taxonomic group to be 19 C, 35 H, and 46 E. Across all our sites in total we found 4 C, 6 H, and 14 E. Our study is less extensive by sampling area and effort, but a roughly similar ratio was found and many species from our study were also detected in theirs: two Clavariaceae (*Clavaria* cf. *acuta* Sowerby [“pointed fairy club”], *C.* cf. *fragilis*), all six of our *Hygrocybe* and *Cuphophyllus* species, and over a third of our *Entoloma* species (*Entoloma* cf. *griseocyaneum* (Fr.) P. Kumm. [“felted pinkgill”], *Entoloma incanum* (Fr.) Hesler [“mouse-scented mushroom”], *Entoloma sericellum* (Fr.) P. Kumm. [“cream pinkgill”], *E. sericeum*, and *Entoloma undatum* (Fr.) M.M. Moser [“wavy Entoloma”]). Other waxcap grassland surveys produced differing CHE ratios, especially having more *Hygrocybe* and fewer *Entoloma* species (Rotheroe *et al.* 1996; Rotheroe 2001).

Mycological red lists have been produced for many European countries. Comparing our survey with a preliminary red list from sand dunes and grasslands in the Netherlands (Arnolds 1989a) yields insights into which taxa occur in grasslands across continents and may belong on red lists for North America. In common between Ontario and the Netherlands were *Cuphophyllus pratensis* (Fr.) Bon (“meadow waxcap”), *C. virgineus*, *Cyathus stercoreus* (Schwein.) De Toni (“dung-loving bird’s nest”), *E. incanum*, *Entoloma* cf. *excentricum* Bres. (“excentric pinkgill”), *Entoloma mougeotii* Fr. ex P. Kumm., *H. conica* (group), *Hygrocybe glutinipes* Bon. (“glutinous waxcap”), *Hygrocybe flavescens* (Kauffman) Singer (“golden waxcap”), *Phallus hadriani* Vent. (“dune stinkhorn”), and *Ramariopsis subtilis* (Pers.) R.H. Petersen (“slender coral”). Greater and more focussed survey efforts for these species should be conducted in North America to determine if their populations are declining as they are in the Netherlands, perhaps due to similar pressures (particularly grassland habitat loss). Our fruiting body surveys detected no species of *Conocybe*, *Dermoloma*, *Lepiota*, *Lepista*, *Psathyrella*, *Psilocybe*, *Tulostoma*, or *Volvariella*, all found in Netherlands grasslands, although some related sequences were detected below-ground (OTUs of the Agaricaceae, Bolbitiaceae, Pluteaceae, Psathyrellaceae, and unknown minor clades; Supplementary Data Sheet C; Hay *et al.* 2018). Differences may be reconciled with the Netherlands studies having sampled over a longer period and across more sites, perhaps representing a

greater variety of habitats than our tallgrass prairie sites. More research is needed in North America to determine which taxa occur in tallgrass versus other prairies, such as *Tulostoma* and *Volvariella* that have only been found in mixedgrass prairie (Hay 2013).

Several species in our survey are new or interesting records. *Entoloma tubaeforme* T.H. Li, E. Battistin, W.Q. Deng & M. Gelardi has only been recorded from under Australian Pine (*Casuarina equisetifolia* L.) in China. Although we did not conduct microscopy prior to destroying our specimen for sequencing, our specimen and theirs appear macromorphologically identical and our sequence and theirs are distinct from other *Entoloma* spp. when placed on a curated phylogram (Battistin *et al.* 2014; our phylogram not shown). Few records exist in MyCoPortal for *Hebeloma dunense* L. Corb. & R. Heim (“dune poisonpie”); it has been recorded from sand dunes in Oregon, DBG-F-016550 and deciduous forest in Quebec, HRL1069. Our *Hebeloma vaccinum* Romagnesi (“willow poisonpie”) specimen is the first record of this species from Canada. We found abundant *C. undulata* in only one of our sites, on open sand amongst moss. It is rarely mentioned in the literature (see *Stereum tenerrimum* Berk. & Rav. and *Stereum exiguum* (Peck) Burt as cited in Reid 1965; Kout and Zibarová 2013), though there are several records on MyCoPortal from across North America. Ours is only the second sequence available on GenBank and one of a few specimens from Canada.

Psathyrella ammophila (Durieu & Lév.) P.D. Orton (“dune brittlestem”) was another species limited to our sandy soil sites. This species is known from sand dunes and especially in relationship with beachgrass roots (*Ammophila* spp.; Watling and Rotheroe 1989) or, in this case, apparently species of other prairie grasses (*Ammophila* spp. were not present in our sites). Both *C. undulata* and *P. ammophila* were absent from the Netherlands grassland and dune preliminary red lists of Arnolds (1989a), but may be of conservation interest in North America. *Polyporus cryptopus* was not found in our surveys, but if it is rare and declining it would be an ideal candidate species for conservation of grassland fungi in North America given its ease of identification.

Although it is difficult to compare NGS studies with different objectives, methods (including primers used), taxonomic scope and scale, some commonalities and differences are apparent. Minor clades Clavariaceae and Hygrophoraceae, which showed high OTU richness in Ontario prairies, were represented among the most abundant genera of Oklahoma tallgrass prairie samples (*Camarophyllopsis* and *Cuphophyllus*, as *Camarophyllus*; Penton *et al.* 2013). No conclusions as to the richness or abundance of these two families can be drawn from a study of Kansas tallgrass prairie (Jumpson *et al.* 2010) except that genus *Hygrocybe* was detected and no genera of the Clavariaceae are listed. In Kansas, the Atheliales was the third most abundant

order, holding 21% of Basidiomycota sequences, whereas in our study the Atheliaceae (=Atheliales; Jülich 1981) had low total relative abundance (less than 1%; Supplementary Data Sheet D; Hay *et al.* 2018). Unique to our study were the Entolomataceae and Sebacinaceae (second and third most OTU rich minor clades) that were not detected in Kansas and Oklahoma prairies (Jumpponen *et al.* 2010; Penton *et al.* 2013). Similarly, a recent NGS study in grasslands of Wales, United Kingdom found many Clavariaceae and Hygrophoraceae but many fewer Entolomataceae and Sebacinaceae than in our study (Detheridge *et al.* 2018; Gareth Griffith pers. comm. 7 August 2018). It is unclear whether methodological factors (e.g., primers used) or site factors are behind these coarse-scale disparities. Our use of primers to the D1 region of the large ribosomal subunit, instead of part or all of the internal transcribed spacer region, may have reduced the bias towards Ascomycota, with their often shorter (and thus more readily PCR-amplified) ITS region (Asemaninejad *et al.* 2016). A comparison of raw sequence files from each study processed side-by-side would yield more detailed and authoritative comparisons. However, each geographic region should be sampled using the same methods and primers, ideally with multiple primers that might compensate for PCR bias, lack of resolution, or gaps in the reference database of any one primer set (Seifert *et al.* 2007; Asemaninejad *et al.* 2016; De Filippis *et al.* 2017). More NGS studies in North American grasslands could determine fungal composition and how it is shaped by soil condition, vegetative community, grassland management regime, and climate (c.f., Detheridge *et al.* 2018).

Comparing above- and below-ground survey techniques

Several studies of fungal communities have compared fruiting body surveys and below-ground molecular techniques (Table 5). Different sampling environments and methods probably explain discrepancies. Fruiting body sampling period varied from one (our study) to four years (Smith *et al.* 2007) with more or fewer site visits, and below-ground techniques were either cloning (Smith *et al.* 2007; Porter *et al.* 2008) or NGS (Ovaskainen *et al.* 2013; our study), with varying numbers of soil or wood samples collected. Earlier studies of ectomycorrhizal fungi comparing fruiting body surveys with root tip mycorrhizae often compared above- and below-ground results and found little correspondence (reviewed by Horton and Bruns 2001). Smith *et al.* (2007) attribute apparent lack of overlap with sampling difficulties and methodology. They showed that greater correspondence can be found by conducting fruiting body sampling visits over multiple years, making equal effort to find all fruiting body forms (epigeous, hypogeous, and resupinate species). However, even with Smith *et al.*'s (2007) greater sampling effort, more than half of their species were not found by both techniques. Taxa with inconspicuous

corticoid fruiting bodies such as Sebacinaceae and Atheliaceae that we failed to detect above-ground were also missed by the thorough fruiting body surveys of Porter *et al.* (2008). Smith *et al.* (2007) were able to detect fruiting bodies of four species of the order Sebacinales, but this is only a fraction of the 15 Sebacinaceae OTUs found in our study.

In other cases, minor clades were not completely exclusive to one method or the other but were disproportionately represented. For example, richness of Clavariaceae was better revealed through below-ground sampling in our study. As suggested by Smith *et al.* (2007), it could be that inconspicuous corticoid or hypogeous species were overlooked due to infrequent fruiting, or species were cryptic (e.g., Clavariaceae: *C. acuta* and *C. fragilis* are both white fairy clubs that were initially recorded as one morphospecies but which we later identified through sequencing). It has been proposed that imbalanced representation of abundance across above- and below-ground techniques may represent different life history strategies: allocate energy into spore release via above-ground fruiting bodies or compete vegetatively below-ground (Gardes and Bruns 1996; Horton and Bruns 2001). Ovaskainen *et al.* (2013) found that among wood-decomposing fungi, there is no tradeoff; species with many fruiting bodies also have more mycelium. These authors outlined several different types of species-specific life-history strategies. Our limited above-ground sampling was not suited to identify life-history tradeoffs.

At coarse taxonomic scales, Porter *et al.* (2008) found that species-rich orders were detected using either above- or below-ground techniques but some, less species-rich orders, were missed by either technique on its own. In contrast, we found that at the major clade level (ca. order) NGS was able to detect all above-ground taxa whereas fruiting body sampling still missed many below-ground taxa. However, most species-rich taxa were still found by either technique at the minor clade (ca. family) level. In general, we found that in a grassland ecosystem, NGS produced more thorough assessments of fungal composition more efficiently than fruiting body surveys. The opposite conclusion is drawn in studies of fungi in treed ecosystems, at least with the molecular methods used for below-ground surveys of the time (Porter *et al.* 2008; Tóth and Barta 2010). Fungi in more arid ecosystems fruit infrequently, so below-ground molecular techniques are probably more practical (noted in Gardes and Bruns 1996). In our study and all others comparing above- and below-ground techniques, using multiple techniques helped discover a more complete view of the ecosystem's fungal composition, but consideration of the ecosystem, taxa of interest, and study objectives can determine which technique(s) would be most appropriate.

Limitations in methods

Sequencing of DNA from soil samples has been criticized for including inactive fungal material when only

TABLE 5. Statistical review of our and three other studies that collected data above-ground (fruiting body surveys) and below-ground (molecular surveys from soil or wood samples) to compare numbers of shared species (species detected by both above-ground and below-ground methods).

Study	Our study	Ovaskainen <i>et al.</i> (2013)	Porter <i>et al.</i> (2008)	Smith <i>et al.</i> (2007)
Environment	tallgrass prairies	Norway spruce (<i>Picea abies</i> (L.) H. Karst.) logs	Hemlock (<i>Tsuga canadensis</i> (L.) Carrière) dominated forest	xeric oak (<i>Quercus</i>) woodland
Shared above-ground (shared / total above)	11%	30%	11%	42%
Shared below-ground (shared / total below)	3%	23%	25%	45%
Shared (species count)	8	30	13	39
Above (species count)	70	99	119	92
Below(species count)	238	133	53	86

active fungal material should be included (Klein 2015). Our soil washing procedure helped to address this by washing away spores (inactive fungal material) and retaining only plant debris, fungal hyphae, rhizomorphs, and sclerotia (Thorn *et al.* 1996; Lynch and Thorn 2006). One drawback was that our two most abundant below-ground species are probably overrepresented: *M. polyspora* produces bulbils 0.1–0.2 mm in diameter (Weresub and LeClair 1971) and members of the Ceratobasidiaceae (potentially our Ceratobasidiaceae sp. 1) produce sclerotia 0.25–0.50 mm in diameter (Kumar *et al.* 2002). These would have been selectively retained on our soil-washing sieves.

Although reference sequence datasets are constantly growing, data gaps still exist. The gaps may represent known fungi yet to be sequenced or fungi that are undescribed, perhaps due to lack of conspicuous fruiting body production or an inability to culture. Queries of OTUs from some of our minor clades unique to the below-ground sampling technique (e.g., Gomphales subclade, Pluteaceae, Cantharellales unknown family, and Russulales unknown family) did not return any confident GenBank matches. Our Pluteaceae minor clade may correspond with a “sister clade to *Volvariella*” (Lynch and Thorn 2006; Bahnmann 2009) and “Pluteoid clade” (Wong 2012) that continues to lack reference sequences from closely related taxa.

Given the short read lengths obtained with Illumina platforms of NGS, annotating OTUs to species-level is difficult and uncertain, and probably is the main reason that comparisons with fruiting body surveys are not usually attempted (Ovaskainen *et al.* 2013). We expect there are a greater number of shared species than the eight we found with identical sequences between our techniques. Our ability to detect more shared species was limited due to some unsuccessful fruiting body sequencing and the requirement of short sequences for NGS (making intra-specific gene variation difficult to account for). The expected true number of shared species can be extrapolated to 15, assuming all fruiting body species we encountered were successfully sequenced. Degrees of gene variation are more difficult

to account for and vary depending on the taxon and gene region in question. Some taxa lacked sufficient variation in the D1 LSU region to distinguish species (e.g., our Polyporaceae *sensu lato* OTUs) whereas other taxa seemed to be variable enough to produce a split between morphological and genetic species (e.g., *M. elegans* which was found by both techniques but not with identical sequences).

Confident identification and sequencing of fruiting bodies was sometimes limited by availability of material from the field for sequencing and microscopy work. For example, small whitish *Mycena* (*sensu lato*) were abundant and recurring in our study, but often occurred singly, providing limited material for microscopy and molecular work. A few distinct *Mycena sensu stricto* species and *Atheniella* cf. *flavoalba* (Fr.) Redhead, Moncalvo, Vilgalys, Desjardin, B.A. Perry (“ivory bonnet”) were distinguished with microscopy and sequencing. Our unidentified *Mycena* sp. (*sensu lato*, white) could belong to *Mycena* (*sensu stricto*), *Hemimycena*, *Delicatula*, or *Atheniella*, which may appear superficially similar but actually cross three families. Two below-ground OTUs (*M. epipterygia* sp. 1 and *Mycena* sp. 2) were particularly abundant and may correspond with above-ground, unsequenced *Mycena* species. *Mycena epipterygia* and *A. flavoalba* were found in European grassland surveys (Wilkins and Patrick 1939; Gumińska 1976; Arnolds 1981). Such difficult taxa benefit from studies that include more frequent surveying than ours to increase chances of finding abundant fruitings, as well as ample time dedicated to careful and extended microscopy and consulting the taxonomic literature.

Conclusions

Our surveys of above- and below-ground fungal taxa showed that most Ontario tallgrass prairie Agaricomycete species belonged to the Clavariaceae, Entolomataceae, Sebacinaceae, Hygrophoraceae, and Polyporaceae *sensu lato*. Inconspicuous taxa such as the Sebacinaceae and Polyporaceae were only revealed with NGS technology. Similarly to previous studies,

we found little correspondence between our above- and below-ground techniques at finer taxonomic scales and greater overlap at coarser scales, but NGS uncovered many taxa that fruiting body surveys missed. Thus, we stress the importance of methodological details in comparing techniques. NGS is a practical technique to determine grassland fungal community composition, but fruiting body surveys remain an important supplement and should not be neglected. In our relatively short fruiting body survey, and using recent advancements in technology (NGS, newly developed primers, and a more comprehensive GenBank reference sequence database), we took the first steps into defining Agaricomycete communities in Ontario tallgrass prairies. More research is needed to discover and better understand the fungal communities of grasslands across North America.

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SUPPLEMENTARY MATERIAL:

Spreadsheets containing metadata and data are available from *The Canadian Field-Naturalist* and from the Dryad Digital Repository: <https://doi.org/10.5061/dryad.sm0kk00>.

Sheet A. Above-ground (mushroom) species, authority, and associated minor (ca. family) and major (ca. order) clade placement.

Sheet B. Above-ground (mushroom) data as individuals across site visits.

Sheet C. Below-ground (soil sample rDNA) OTU (Operational Taxonomic Unit) taxonomic annotations, and associated minor (ca. family) and major (ca. order) clade placement.

Sheet D. Below-ground (soil sample rDNA) data as OTU (Operational Taxonomic Unit) reads per site visit.

Sheet E. Raw data for all specimens (above-ground, i.e., mushrooms) collected or otherwise recorded as observations in this study.

Book Reviews

Book Review Editor's Note: *The Canadian Field-Naturalist* is a peer-reviewed scientific journal publishing papers on ecology, behaviour, taxonomy, conservation, and other topics relevant to Canadian natural history. In line with this mandate, we review books with a Canadian connection, including those on any species (native or non-native) that inhabits Canada, as well as books covering topics of global relevance, including climate change, biodiversity, species extinction, habitat loss, evolution, and field research experiences.

Currency Codes: CAD Canadian Dollars, USD US Dollars, EUR Euros, AUD Australian Dollars, GBP British Pound.

HERPETOLOGY

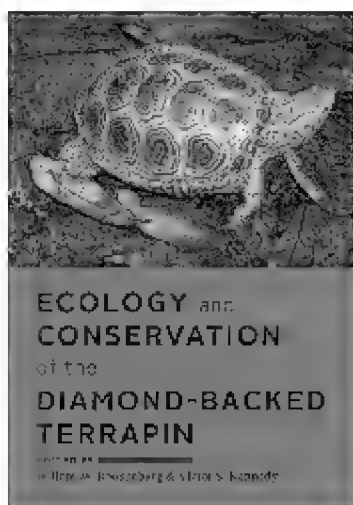
Ecology and Conservation of the Diamond-backed Terrapin

Edited by W.M. Roosenburg and V.S. Kennedy. 2019. Johns Hopkins University Press. 296 pages, 79.95 USD, Cloth or E-book.

Diamond-backed Terrapin (*Malaclemys terrapin*) lives in estuaries in the United States from Massachusetts to Texas. Most species of turtles are associated with freshwater and a few are found in the oceans (sea turtles), but the Diamond-backed Terrapin is the only turtle species to permanently reside in brackish water, the narrow interface between the full saltwater of the ocean and the freshwater of the inland lakes and rivers. It is closely related to the map turtles, and the species share characteristics such as females being substantially larger than males, and feeding on molluscs and other hard-shelled invertebrates.

During the 19th and early part of the 20th century, Diamond-backed Terrapins were widely collected for food. By 1880, it is estimated that more than 200 000 individuals were caught each year. Philadelphia, New York City, and Baltimore were some of the larger markets, but Diamond-backed Terrapins were also shipped live to England, France, and Germany. Prices were as high as \$125 a dozen by the early 1900s, but by 1938, prices had dropped to \$36 a dozen because of declining demand. Nonetheless, the commercial harvest of Diamond-backed Terrapins caused the collapse of many populations.

This book collects together review papers on various topics related to the biology and conservation of this wide-ranging species. The book begins with an introduction by J. Whitfield Gibbons, a veteran turtle researcher. Part I, Biology and Ecology, includes 11 papers on field techniques, evolutionary history, taxonomy, genetics, geographic variation, reproductive behaviour, hatchling behaviour, osmoregulation, temperature-dependent sex determination, habitat use, and environmental toxicology. Part II, Fisheries and Con-



servation Challenges, includes seven papers on commercial harvest, habitat loss and road mortality, motorboats, bycatch from the crab harvest, environmental education, habitat restoration and head-starting, and concludes with a paper on the future of the Diamond-backed Terrapin. The papers were written by researchers (mainly from universities and government agencies) with experience with Diamond-backed Terrapins from across the range of the species.

The collected papers provide a broad and rich overview on the biology of this turtle. The concluding paper on the future of Diamond-backed Terrapins demonstrates the importance of collaborative work carried out over many years to accomplish conservation goals. And many threats, such as Diamond-backed Terrapins getting caught and drowning in abandoned crab pots set out to catch crabs, are still significant threats after years of work. Viable solutions have been suggested, such as the use of biodegradable panels which would mean that lost or abandoned crab pots would not continue to be death traps for years to come, but work on reducing the mortality from this threat is making only slow progress.

Although all of these papers specifically target Diamond-backed Terrapin, the contents of these papers are broadly applicable to other turtle species. In particular, the sections on threats (e.g., habitat loss, road mortality, and motorboats) and on environmental education are relevant to Canadian freshwater turtles. For example, injuries from boat propellers are a widespread threat for many turtles. Diamond-backed Terrapin research has found that individuals in the water dive deeper when a boat approaches, but only by about 30 cm, which is not enough to avoid being potentially hit by the propeller. In many cases, then, the specific details around Diamond-back Terrapin threats or issues are relevant to other turtle species, making this a highly recommended book for anyone working in turtle biology or conservation.

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ORNITHOLOGY

The Genius of Birds

By Jennifer Ackerman. 2016. Penguin Random House. 340 pages, 23.00 CAD, Paper.

From its striking cover to its detailed index, Jennifer Ackerman delivers a well-crafted popular science book to satisfy enthusiastic birders and armchair naturalists alike. The book is divided into eight chapters plus an Introduction, each with amusing titles such as “Four – Twitter: Social Savvy” and “Three – Boffins: Technical Wizardry”. Each chapter features a delightful



illustration by John Burgoyne picking up on one of the stories or central themes of the chapter; these are excellent additions to the text and follow through on the promise of the Western Scrub Jay cover art by Eunike Nugroho.

As you might expect, much of the content is reasonably cerebral—the short subsections belie their content, and for most folks this will not be a book for drowsy before-bedtime reading. Fortunately, Jennifer Ackerman writes with a rich style that makes cognitive neuroscience research appealing and accessible. Through direct quotes and anecdotes curated from researcher interviews coupled with her own extensive research, the author explores various forms of avian intelligence—problem solving, navigational, musical, and more.

This is a book full of surprises and unknowns, including cutting edge research as well as unanswered questions about common and rare species alike. Not limited to probing accounts of experimental research,

The Genius of Birds is full of cocktail conversation starters. I learned that pigeons are better at intuiting the Monty Hall Dilemma than I am, for example. And that some birds have a keen sense of smell, and may use it to navigate. This is not to say that this volume is just a litany of facts, nor that it strays from its central theme. The book is specialized in its focus: bird learning and intelligence are front and centre. The last chapter is the only one that delves into the ‘big issues’ of biodiversity declines, habitat loss, and climate change in a significant way.

The book is also exquisitely researched and has the largest reference list I’ve seen in a popular science book, with a whopping 54 pages of notes in reduced font size. If you would like more information on a particular topic and have journal subscription privileges, you will not be disappointed. If you forget where in the 266 content pages you read an interesting tidbit, there is also a detailed index so you can retrace your steps.

If you start the first page of *The Genius of Birds* thinking that birds are simple automatons incapable of logic or reasoning, you are in for a shock. If you came in already believing that birds are intelligent beings, you will turn the last page astounded by just how true that really is. I recommend this book to anyone looking for an in-depth read on bird intelligence, who wants to understand more about our feathered friends, and perhaps as a gift to friends and family members who don’t understand why birdwatching is such a popular pastime.

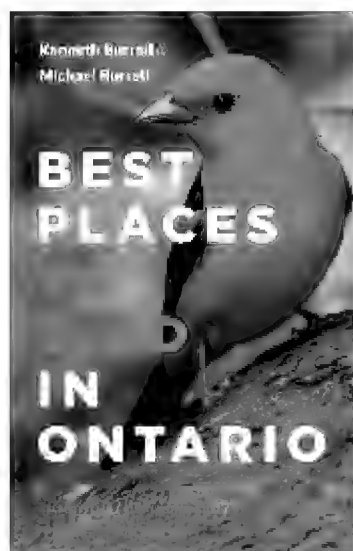
HEATHER A. CRAY

Waterloo, ON, Canada

Best Places to Bird in Ontario

By Kenneth Burrell and Michael Burrell. 2019. Greystone Books. 278 pages, 24.95 CAD, Paper.

A book on where to find birds is a truly valuable tool. It has been a long time since Clive Goodwin’s indispensable *A Bird-Finding Guide to Ontario* (University of Toronto Press, 1982 and revised 1995) and much has changed since then. So periodically someone needs to write a new version to incorporate the changes in the land and the concepts in biology.



The Burrell brothers have now produced *Best Places to Bird in Ontario* to bring us current information. They have chosen 30 of their favourite places to highlight the best Ontario has to offer. Each place is described by a general introduction that familiarises the reader with the local environment. There are instructions on how to get there, whether by road, rail, or aeroplane. (These tend to be a little Toronto-centric.)

There is a well described birding strategy. The authors propose a starting point, a route, and the key places to check for special species. These plans are carefully thought through and appear to be logical (or perhaps I think the same way as the Burrells). I have followed a similar route to that suggested through Point Pelee and

the surrounding area many times, seeing many of the species mentioned at the location highlights.

Each area is accompanied by a location map. Like most recent publications these are clear and easy to read and follow. The Burrells have added locations that are particularly relevant to birdwatchers. Only birders will understand the significance of Pelee's "Serengeti" tree or Rose Lane on Canoe Lake Road or the sewage lagoons at Moosonee. This makes these the most useful birding maps I have seen.

Writers of this type of book must reflect a good level of enthusiasm. They need to paint a rosy picture of each site; after all they are their favourites. Is the zeal in this book warranted? It depends on the site. I have been going to Presqu'île Provincial Park (PIPP) for years. In the spring it has a flood of waterfowl and the fall is shorebird season. Even on a bad day you should get a good count of these birds, and a good day can be wonderful. For a place like Algonquin Provincial Park (APP) it is very different. Recently I reviewed the last 10 day trips my regular birding group took to APP. We go every year to look for 10 boreal species. We have a 24% success rate seeing those species and average of 2.2 species of the 10 per trip. As one of those species is always Canada Jay these results are not impressive. The difference is PIPP is filled with visible migrants, whereas APP has a group of elusive forest dwellers. The APP birds are always there and seen every week by somebody, but usually on different days of the week.

Pelee is a different case. The authors think this is the best birding spot in Ontario and I strongly agree. There are more different species seen and even a few hours in spring will get you an impressive list. My own view is a bit prejudiced because I first went to Pelee in the 1960s. Then the park was visited by two dozen birders a day (we all knew each other) and there were higher numbers of individual birds than today. In spring, trees near the point would be loaded with birds and the fall would bring streams of migrants. I used to band raptors (and sleep) at the base of the tip near the hot dog stand. Yes, sadly, it was different, but the Burrells are still correct in their praise. I am planning a spring trip to the USA, so I pulled a guide to New England. The Burrell's book is significantly superior to this, admittedly older, book.

This guide will be of great value to new birders and visitors alike. More experienced people will likely know most of the chosen places. But if they have not been to the more distant spots, like Rainy River or Moosonee, then it is still worth the purchase. I will not be abandoning Goodwin's guide entirely as it covers many more areas than the 30 selected for this guide. Should I be going to one of the favoured 30, however, I will use the new book with enthusiasm.

ROY JOHN

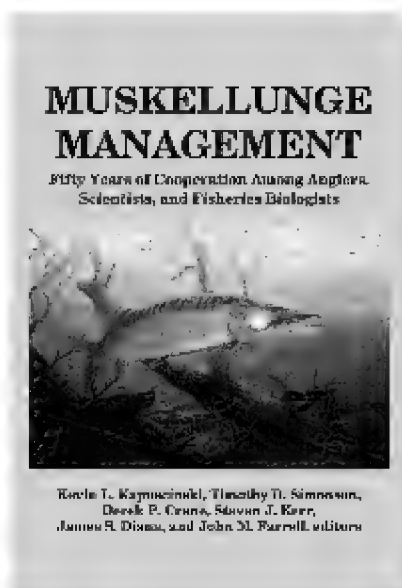
Ottawa, ON, Canada

ZOOLOGY

Muskellunge Management: Fifty Years of Cooperation Among Anglers, Scientists, and Fisheries Biologists

Edited by Kevin Kapuscinski, Timothy Simonson, Derek Crane, Steven Kerr, James Diana, and John Farrell. 2017. American Fisheries Society. 675 pages, 79.00 USD, Cloth.

Muskellunge (*Esox maskinongy*) is a freshwater apex predatory fish whose native range revolves around the Great Lakes region of North America. Because this species is long-lived and can grow to an exceptional size (approximately 160 cm), it has attracted continuing attention throughout recent history from an indigenous subsistence harvest, recreational anglers, and commercial netting operations. Inhabiting waters close to human population centres and the accompanying agricultural/industrial development, it has been impacted by water pollution, habitat degradation, and invasive species, as well as overfishing and harvesting.



In support, modern Muskellunge fisheries management encompasses all the administrative actions, procedures, and regulations developed and implemented, usually by a government agency, to restore, maintain, or enhance the biological and economic potential of the fish species in a body of water.

During the last 50 years, anglers in pursuit of Muskellunge have banded together to form muskie clubs specific to this species and promote public education, conservation, scientific research, fish data collection, and artificial propagation where necessary. In cooperation with the American Fisheries Society, academic researchers, fishery biologists, and clubs like Muskies Inc. and Muskies Canada, this textbook sized compendium of almost 700 pages reflects the proceedings of the Hugh Becker Memorial Muskie Symposium which was held in Minnesota during 2016. Containing many scientific papers, extended abstracts, and regional reports, *Muskellunge Management* demonstrates thematically 50 years of cooperation among anglers, scientists, and fisheries management concerns.

This book is primarily aimed at the fisheries management community across North America as well as scientists and researchers interested in this animal. Its state-of-the-art papers are organized into eight sections: 50 years of cooperative efforts, biology, habitat, population dynamics, genetics, population assessments, regional management approaches, and stocking and propagation. Essentially, these form a broad spectrum of papers on many aspects and issues related to Muskellunge.

As an example of the partnerships section, Muskies Canada, working with natural resource agencies, is seeking to ensure sustainable wild Muskellunge populations through habitat protection, restoration, and enhanced regulation. In contrast, in the United States, much more emphasis is placed on artificial propagation/stocking and also range extension across its continental geography. To support some of the Canadian objectives, muskie anglers are encouraged to enter angling information online, including waterbody location, data on fish captured, and amount of fishing effort. With this yearly data collection, large scale changes to fish size and abundance can be monitored by management agencies. For the curious, in 2018 within Ontario over 1400 captures were recorded by participants. On average it took about 16 hours of angling effort to record one capture of a Muskellunge.

In 1984 during a previous Muskellunge symposium, genetic research was identified as a priority future requirement. In this issue, a sizeable number of papers highlight the significant genetic diversity among native populations of this single species across its range. The genetic data appears to substantiate the reality of three distinct regional lineages derived from a single Mississippian glacial refugium population. Each lineage can be broken down to multiple subgroups impacted by local geography, spawning fidelity, proximity to each other, and habitat connectivity. For example, around the City of Ottawa, native Ottawa River Muskellunge above and below the city form different subgroups and the Muskellunge of the Rideau River tributary form a third genetic subgroup. The Chaudière and Rideau falls within the City contribute to these genetic differences. This can be compared to the Trent Severn system of the Kawartha lakes where the Muskellunge show little to no genetic substructure over a comparably more extensive geography.

Several papers detail the attempt to restore a self-supporting population of Muskellunge in Ontario's Lake

Simcoe. The species was essentially extirpated in the lake during the early part of the last century, mostly through commercial harvest and habitat loss. Over the last 14 years, millions of dollars, and multiple partners, more than 10 000 young-of-the-year Muskellunge have been stocked into Lake Simcoe. This project has wrapped up and now it is up to the animal. Biologists estimated that it will take another 15 years of monitoring to determine if this project will result in a successful restoration—a new self-sustaining population.

Interestingly enough, other articles call attention to an opposite ecological dilemma happening to the east. As the story goes, Muskellunge were introduced by Quebec provincial authorities, in efforts to increase sportfishing opportunity, to a headwater lake. Over time the Muskellunge emigrated and set up populations along the St. John River watershed throughout Maine and New Brunswick to points downstream of the City of Fredericton. Currently these fish are considered an invasive species subject to active efforts of elimination by government management agencies despite their increasing popularity as a sportfish.

For many decades the upper St. Lawrence River has long been considered mythical as harbouring some of the largest growing specimens of this animal on the continent. Despite many recent management efforts, researchers indicate it is suffering a continuing population decline triggered at least in part by fairly recent invasive species, such as the outbreak of viral hemorrhagic septicaemia causing adult die offs and staggering numbers of the Eurasian Round Goby which act as an egg predator limiting recruitment. Recommendations include management plans to enhance young-of-the-year recruitment with actions to restore high quality spawning and nursery habitat.

Within this substantial volume, much more subject matter touches on many issues, including non-lethal tissue sampling, weight estimates, tournament impacts, response to catch and release, nursery habitat, population assessment, regional management perspectives, and many others. Based on the partnership of an increasing number of concerned and dedicated non-profit muskie clubs, resource managers are forging biologically sound research and management efforts. The book *Muskellunge Management* provides a solid foundation for a potentially bright future.

HEDRIK WACHELKA

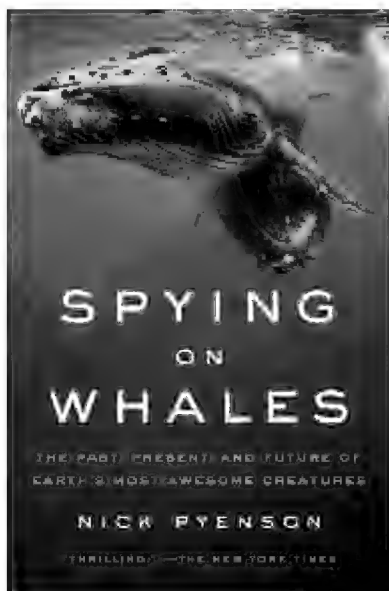
Muskies Canada Inc., Ottawa, ON, Canada

Spying on Whales

By Nick Pyenson. 2018. Viking. 336 pages, 27.00 USD, Cloth, 17.50 USD, Audiobook, 13.99 USD, E-book.

Spying on Whales is a book full of interesting facts about the biology and ecology of whales. The author, Nick Pyenson, is the curator of fossil marine mammals at the Smithsonian Institution's National Museum of Natural History, and has been studying whales for many years. The book is structured in a unique but intriguing style: the author interweaves a narrative of the past, present, and future of whales with his own field excursions to study whales. As a paleontologist, the author often studies the fossilized bones of whales, but he also compares this to contemporary samples taken from whaling stations, and he presents the information in a compelling way by relating his discoveries to the form and function of whales. Throughout the book, he describes some of the basic biology of whales, such as how and why Blue Whales evolved their gigantic sizes, and how Fin Whales and other rorqual whales withstand the shear force of opening their mouth while lunge feeding. Within this narrative, the author describes the mysteries of whale evolution, teasing apart the history of how current behemoths of the ocean evolved from relatively small terrestrial mammals. He also discusses the future of whales, and how they might adapt to changes brought on by climate change and human activity.

As an ecologist who studies whales, I found this book to be quite compelling, but that may be due to my own biases. Any naturalist interested in marine mammals should find this book intriguing. It is written in clear language, and although the author does present some details of the science behind the narrative that he tells, he doesn't get too bogged down in the details, and most readers without an education in science should still find the book accessible and interesting. One warning for any squeamish readers: the author does spend some time discussing field trips to past and current whaling stations, and describes how whales are processed in gruesome detail. He fully justifies his own use of whales killed by whaling operations for his research—he reasons that it is completely ethical and is a good use of dead whales that were going to be killed regardless of his research. Even still, the whole enterprise of commercial whaling might be too much for some readers.



I found a somewhat troubling error in the book that bothered me about Bowhead Whales in the Bering-Chukchi-Beaufort (BCB) stock, a population near and dear to me because I study it. The author states that the explorer Sir John Franklin likely saw Bowhead Whales from this population while on board the *Erebus* near King William Island, which is in the central Canadian Arctic Archipelago. This is extremely unlikely, however, as the BCB stock summers in the eastern Beaufort Sea, Amundsen Gulf, and Viscount Melville Sound and, to the best of my knowledge, whales from this stock have never been documented near King William Island. Franklin would likely have seen plenty of Bowhead Whales from the eastern Canada-west Greenland (ECWG) stock when he and his crew travelled from England to Baffin Bay, and then deeper into the Canadian Arctic Archipelago from the east. The ECWG stock spends its time in the eastern Canadian Arctic around Baffin Island, and ranges much more closely to King William Island than the BCB population does. However, the current range of the ECWG stock doesn't even overlap with King William Island, so perhaps Franklin didn't observe any Bowhead Whales while he was near King William Island. Given that Franklin's expedition was more than 150 years ago and species distributions can change through time, it is possible that these Bowhead Whale populations lived in slightly different areas during that time. However, it is unlikely that the distributions of either population would have shifted toward King William Island because summer sea ice concentration should have been even higher in the 1800s than it is now, and patterns in sea ice dictate where Bowhead Whales spend their winters and summers, as well as the timing of their migrations. Both populations currently spend their winters quite far away from King William Island, and increased summer sea ice concentration would make it more difficult for whales from either population to migrate to King William Island.

Overall, *Spying on Whales* was a pleasure to read, and provided me with plenty of tidbits about whale biology and evolutionary history that I was not aware of before reading this book. I highly recommend this book to any naturalists interested in evolution, whales, or paleontology.

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NEW TITLES

Prepared by Barry Cottam

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BOTANY

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Fungipedia: A Brief Compendium of Mushroom Lore. By Lawrence Millman. 2019. Princeton University Press. 208 pages, 16.95 USD, Cloth or E-book.

The Nature of Plants: An Introduction to How Plants Work. By Craig N. Huegel. 2019. University Press of Florida. 288 pages, 24.95 USD, Paper.

Plant Evolutionary Developmental Biology: The Evolvability of the Phenotype. By Alessandro Minelli. Photographs by Maria Pia Mannucci. 2018. Cambridge University Press. 468 pages, 84.99 USD, Cloth, 68.00 USD, E-book.

Sedges of The Northern Forest – A Photographic Guide. By Jerry Jenkins. 2019. Cornell University Press. 96 pages, 16.95 USD, Paper.

Sedges of the Northern Forest – Quick Guide. By Jerry Jenkins. 2019. Cornell University Press. 4 pages, 11.95 USD, Fold-out Chart.

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The Lives of Bees: The Untold Story of the Honey Bee in the Wild. By Thomas D. Seeley. 2019. Prince-

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ZOOLOGY

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Bats: An Illustrated Guide to All Species. By Mari-
anne Taylor. Photographs by Merlin Tuttle. 2019. Smithsonian Books. 400 pages, 29.95 USD, Cloth.

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OTHER

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Animal Beauty: On the Evolution of Biological Aesthetics. By Christiane Nüsslein-Volhard. Translated by Jonathan Howard. 2019. MIT Press. 128 pages and 47 colour illustrations, 14.95 USD, Cloth.

The Anthropocene as a Geological Time Unit: A Guide to the Scientific Evidence and Current Debate. Edited by Jan Zalasiewicz, Colin N. Waters, Mark Williams, and Colin Summerhayes. 2019. Cambridge University Press. 382 pages, 62.99 USD, Cloth.

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Complexity: The Evolution of Earth's Biodiversity and the Future of Humanity. By William C. Burger. 2016. Prometheus Books. 380 pages, 26.00 USD, Cloth, 11.99 USD, E-book.

Corridor Ecology, Second Edition: Linking Landscapes for Biodiversity Conservation and Climate Adaptation. By Jodi A. Hilty, Annika T.H. Keeley, William Z. Lidicker Jr., and Adina M. Merenlender. 2019. Island Press. 368 pages, 40.00 CAD, Paper or E-book.

***Darwin Comes to Town: How the Urban Jungle Drives Evolution.** By Menno Schilthuizen. 2018. Picador. 304 pages, 27.00 USD, Cloth, 18.00 USD, Paper, 9.99 USD, E-book.

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The Nature of Canada. Edited by Colin M. Coates and Graeme Wynn. 2019. UBC Press, On Point Press. 320 pages, 29.95 CAD, Paper.

†The New Beachcomber's Guide to the Pacific Northwest: Alaska to Oregon, 2019 Edition. By J. Duane Sept. 2019. Harbour Publishing. 432 pages and 400 colour photos, 32.95 CAD, Paper.

Nature Rx: Improving College-Student Mental Health. By Donald A. Rakow and Gregory T. Eells. 2019. Cornell University Press, Comstock Publishing Associates. 108 pages, 14.95 USD, Paper.

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Poached: Inside the Dark World of Wildlife Trafficking. By Rachel Love Nuwer. 2018. Da Capo Press. 384 pages, 36.50 CAD, Cloth.

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There Is No Planet B: A Handbook for the Make or Break Years. By Mike Berners-Lee. 2019. Cambridge University Press. 302 pages, 12.95 USD, Paper.

Wildlife Gardening: For Everyone and Everything. By Kate Bradbury. 2019. Bloomsbury Wildlife. 176 pages and 300 colour photographs, 14.99 GBP, Paper. Also available as an E-book.

The Wood for the Trees: One Man's Long View of Nature. By Richard Fortey. 2017. Knopf / Vintage. 336 pages, 18.00 USD, Paper, 12.99 USD, E-book.

A Year on the Wild Side. By Briony Penn. 2019. Touchwood Editions. 400 pages, 26.00 CAD, Paper.

News and Comment

Upcoming Meetings and Workshops

Plant Canada 2019

Plant Canada 2019 to be held 7–10 July 2019 at the University of Guelph, Guelph, Ontario. The theme of the conference is: ‘Communicating innovation in plant

science’. Registration is currently open. More information is available at <http://www.cspb-scbv.ca/PlantCanada2019/index.shtml>.

Mothapalooza

Mothapalooza to be held 12–14 July 2019 at the Shawnee Lodge & Conference Center, West Portsmouth, Ohio. The 2019 Conference Moth is the Sooty-winged

Chalcoela (*Chalcoela iphitalis*). More information is available at <http://www.mothapalooza.org/>.

Northeast Partners in Amphibian and Reptile Conservation Annual Meeting

The Northeast Partners in Amphibian and Reptile Conservation (NEPARC) Annual Meeting to be held 17–19 July 2019 at Stockton University, Galloway, New Jersey. The theme of the conference is: ‘20 Years of

NEPARC – Back to New Jersey’. Registration is currently open. More information is available at <http://northeastparc.org/next-meeting-info/>.

Behavior 2019

The joint meeting of the 56th Annual Conference of the Animal Behavior Society and the 36th International Ethological Conference to be held 23–27 July 2019 at

the University of Illinois, Chicago, Illinois. Registration is currently open. More information is available at <http://www.animalbehaviorsociety.org/2019/>.

Botany 2019

Botany 2019 to be held 27–31 July 2019 at Starr Pass, Tucson, Arizona. Registration is currently open. More

information is available at <https://2019.botanyconference.org/>.

Symposium on the Conservation and Biology of Tortoises and Freshwater Turtles

The 17th annual Symposium on the Conservation and Biology of Tortoises and Freshwater Turtles, co-hosted by the Turtle Survival Alliance and the IUCN Tortoise and Freshwater Turtle Specialist Group, to be held 4–

8 August 2019 at the Loews Ventana Canyon Resort, Tucson, Arizona. Registration is currently open. More information is available at <https://turtlesurvival.org/2019symposium/>.

2019 Mycological Society of America Meeting

The 2019 meeting of the Mycological Society of America to be held 10–14 August 2019 at the University of Minnesota, Minneapolis, Minnesota. The theme of the

conference is: ‘Diversity in All Dimensions’. Registration is currently open. More information is available at <https://msafungi.org/2019-annual-meeting/>.

Ecological Society of America and United States Society for Ecological Economics Joint Meeting

The 104th annual meeting of the Ecological Society of America in partnership with the United States Society for Ecological Economics to be held 11–16 August 2019 at the Kentucky International Convention Center, Louisville, Kentucky. The theme of the conference is:

‘Bridging Communities & Ecosystems: Inclusion as an Ecological Imperative’. Registration is currently open. More information is available at <https://esa.org/louisville/>.

Canadian Society for Ecology & Evolution, Entomological Society of Canada, and Acadian Entomological Society Joint Meeting

The joint meeting of the Canadian Society for Ecology & Evolution, Entomological Society of Canada, and Acadian Entomological Society to be held 18–21 August 2019 at the Fredericton Convention Centre, Fred-

ericton, New Brunswick. Registration is currently open. More information is available at <http://csee-esc2019.ca/index.html>.

2019 International Conference on Ecology & Transportation

The 10th biennial International Conference on Ecology & Transportation, hosted by the California Department of Transportation and California Department of Fish and Wildlife, to be held 22–26 August 2019 at the Hyatt

Regency Hotel, Sacramento, California. Registration is currently open. More information is available at <https://icoet.net/>.

Society of Canadian Ornithologists – Societe des ornithologistes du Canada

The 36th meeting of the Society of Canadian Ornithologists – Societe des ornithologistes du Canada to be held 27–30 August 2019 at the Hôtel Chateau Laurier,

Québec City, Quebec. Registration is currently open. More information is available at <http://sco-soc-quebec2019.org/>.

iNaturalist Canada passes the 1 000 000 observation mark

The value of citizen scientists—and their collaborations with, for want of a better term, “professional” scientists—is becoming increasingly recognized (e.g., Silvertown 2009; Dickinson *et al.* 2012). This is evident in the pages of *The Canadian Field-Naturalist*, including the current issue. For example, in Bowden *et al.* (2018) the combined efforts of citizen scientists, naturalists, and scientists led to an astounding increase in the list of spiders known to occur on Prince Edward Island. They were able to more than quadruple the number of known spider species, from 44 to 198 species! And Mullins *et al.* (2018) were able to leverage public engagement in the Ontario BioBlitz Program, an annual citizen science event, to collect and identify lichen and allied fungus species within the Greater Toronto Area. These data allowed them to increase the list of known lichens and allied fungi species within the region to 180 species.

I chose to highlight one citizen science endeavour—iNaturalist Canada—in this issue because, as of 19 April 2019, it has surpassed the 1 000 000 observation mark. At the time of writing (4 May 2019), this number had already grown to 1 038 803 observations, representing observations of 18 678 species (iNaturalist Canada 2019).

iNaturalist is a place where environmental non-government organizations (ENGOS), academics, government, and citizen scientists come together to work towards an increasing understanding of wildlife in Canada. It was developed by two ENGOS—the Canadian Wildlife Federation and NatureServeCanada—in collaboration with the federal government (Parks Canada) and the Royal Ontario Museum. These Canadian organizations also collaborated with iNaturalist.org (housed in the California Academy of Sciences). These agencies worked together to launch (and maintain) the website and associated app used in data collection. In

addition to these agencies, the success of iNaturalist Canada depends on the contributions of citizen and professional scientists, with (as of 4 May 2019) 25 569 observers (who collect and upload wildlife observations, e.g., photographs) and 10 912 identifiers (who aid in identification of wildlife in photographs; iNaturalist Canada 2019). The cellphone app—which is available in English and French, and downloadable through Google Play or the Apple App Store—makes it easy to contribute to data collection. And the webpage <https://inaturalist.ca/> makes it easy for anyone to benefit from this resource, even if one just wants to enjoy photographs of Canadian wildlife.

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AMANDA E. MARTIN

Assistant Editor – *The Canadian Field-Naturalist*

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